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Contents of previous issues of the JOURNAL OF ANIMAL SCIENCE are indexed in the Agricultural Index which is available in most libraries, and in the November issue of each complete volume of the JOURNAL.

THE ROLE OF THYROIDAL MATERIALS AND OF SYNTHETIC GOITROGENS IN ANIMAL PRODUCTION AND AN APPRAISAL OF THEIR PRACTICAL USE

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Introduction

In the past, the application of knowledge of endocrine processes to animal production has been largely limited by the fact that the necessary glandular extracts have been expensive and that surgical methods, with all their limitations, have had to be used to reduce the production of a particular hormone within the body. In the case of the thyroid gland, it is now possible to produce varying degrees of hyperthyroidism simply by feeding iodinated casein; a hypothyroid condition can be produced readily by feeding synthetic goitrogens such as thiourea, thiouracil, thiobarbital and their derivatives. This is the only endocrine gland in which complete control of internal secretion can be maintained by oral dosage of synthetic materials, though partial control of pancreatic internal secretion by feeding alloxan, and partial control of estrogenic and androgenic hormone secretion by implantation or injection of synthetic sex hormones is well established.

Such control of thyroid status has enormous possibilities in animal production. It is the object of this paper to review the extent of our knowledge of the effect of thyroid secretion status on various aspects of animal productivity. Insofar as present information will permit an attempt has been made to assess the value as well as the hazards involved in regulating the thyroid status in established commercial production.

In the preparation of this paper all available information has been reviewed critically by one or more members of the committee. Because of the paucity of information in many aspects of this field as well as the variability in some of the results that have been reported a conservative approach has been taken. It is hoped that the review will act as an impetus to further investigation.

The review is planned on the basis of the three main classes of livestock—ruminants, swine and poultry. It is preceded by a short note on what materials are available for the control of thyroid secretion status. This presentation makes possible an appraisal at the end of each section of the

[1] The reviewing panel served in the preparation of this paper by invitation of the Editor of The Journal of Animal Science. W. E. Petersen served as panel chairman.

practical possibilities of modification of thyroid status, and was thought a more useful arrangement of material for ease of reference than a review planned on the particular productive functions involved.

The Materials Available for Alteration of Thyroid Secretion Status

Thyroactive Iodinated Proteins

Following many earlier attempts which have been reviewed by Reineke and Turner (1942) and by Reineke (1946a) iodinated casein was prepared in Germany by Ludwig and von Mutzenbecher (1936, 1939), from which thyroxine, the internal secretion of thyroid, was isolated. This was confirmed in England by Harington and Pitt Rivers (1939). The thyroidal potency of such products was erratic and sometimes very low, and the Missouri group (Reineke and Turner (1942), Reineke and Turner (1945a 1946)) greatly improved this iodination process so that iodinated casein, having an apparent thyroxine content of approximately 3 percent and a biological activity many times that of dried thyroid gland, can now be produced. Casein is not essential for activity subsequent to optimal iodination. Serum globulin, silk fibroin, and edestin; (Ludwig and von Mutzenbecher, 1939) serum albumin; (Muus, Coons and Salter, 1941), egg albumin and soya bean protein; (Reineke and Turner 1942) whole blood protein and a commercial peanut protein "ardein" (Pitt Rivers and Randall, 1945; Simpson, Johnston and Traill, 1947) have all been iodinated successfully. Iodinated protein is being produced commercially in the United States and marketed under the registered trade name of "Protamone."[2]

To avoid confusion between such names as "thyrolactin," "thyroprotein," "iodoardein," "Iodocasein," "Protamone," "Deacasein," and "astracasein," any iodinated protein preparation possessing thyroid activity is referred to here simply as "iodinated protein" for the collective term, and "iodinated casein," "iodinated blood protein," etc., for the particular preparations. As pointed out by Reineke (1946b), this has a disadvantage in that the term "iodinated" does not distinguish between the older, biologically inert, iodinated proteins and the highly active ones at present available.

Iodinated casein can be incorporated into dairy cattle feeds without loss of potency, either during the moderately high temperatures of the cubing process or during subsequent storage under farm conditions (Blaxter, 1945b).

Synthetic Goitrogens

Goitrogenic materials can be broadly divided into two classes: those ions

[2] See U. S. patents Nos. 2,329,445, 2,379,842 and 2,385,117.

which interfere with the storage of iodine in the thyroid, and those organic compounds which interfere with the synthesis of thyroxine in the gland. It has been pointed out (Baumann and Metzger, 1947) that the thyroid filters from the circulation, all halogens and other anions (and possible cations) with a similar electron shell pattern, and the thyroid is depleted of iodine by the mass-action-like effect of the administered anion. This only occurs when minimal quantities of iodine are present in the diet and is neutralized by feeding iodine. These ions are of little importance in animal production except insofar as they may be involved in causing congenital goitre in areas where iodine appears normal (Orr and Leitch, 1929; Jamieson, Sampson and Russell, 1945).

The second group includes those organic compounds where goitrogenic effect is not neutralized by feeding excess iodine. These were discovered as a result of work on the goitrogenic action of dietary brassica seed (Kennedy, 1942) and studies of the effect of sulphonamides on the thyroid (MacKenzie, MacKenzie and McCollum, 1941). Many of these compounds were tested by Astwood's group (Astwood, Sullivan, Bissell, and Tyslowitz, 1943, Astwood 1943) who showed that the presence of the thioureylene radical conferred the goitrogenic activity. Thiourea and thiouracil have been most commonly used in animal production studies. Their effects, however, are not synonymous for the lethal dose of thiouracil is only 1/375 that of thiourea (Thyssen, 1945), and the substituted thiouracils, 6-methyl-thiouracil and 6-n-propyl thiouracil are five times more active in humans than thiouracil (Astwood and Vander Laan, 1945). Thiobarbital (5.5'-diethyl-2-thiobarbituric acid), Astwood, Bissell and Hughes, 1945) also has low toxicity and considerable goitrogenic effect at low dosages; in fact, many of the newer goitrogens have not been used in animal production studies at all.

Toxicity of goitrogens to farm livestock has been investigated by Schultze and Turner (1945). Thiourea was markedly toxic to chicks, lambs, cows and goats. No toxic effects of 5 gm. of thiouracil/100 lbs. body weight were noted in the goat or 12 gm. daily of the same drug in the cow, whereas far smaller doses of thiourea resulted either in death or serious toxicity symptoms. These symptoms are not alleviated by thyroxine injection and are, therefore, not the result of incipient hypothyroidism.

The possibility of using structural analogues of thyroxine (Wooley, 1946) for the production of hypothyroidism has not been explored.

Modification of Thyroid Secretion Status in Ruminants

The Effect of Hypothyroidism on Growth and Fattening in the Ruminant

Thyroid extirpation in a ruminant was first reported by vonRapp (1840). Since then many observations have been made on hypothyroidism in these

animals. Ruminants, in fact, were preferred for the earlier thyroidectomy studies, as the operation is easily performed leaving the parathyroids intact —a difficult operation in Carnivora (Marston and Peirce, 1932). Ablation of the thyroid depresses growth. This is true of all animals and has been recorded for sheep (Simpson, 1942; Mangold, 1932; Marston and Peirce 1932; Todd and Wharton, 1934; and Todd, Wharton and Todd, 1938), for the goat (Simpson, 1924; Reineke and Turner, 1941; Reineke, Bergman and Turner, 1941); and for cattle (Brody and Frankenbach, 1942; Spielman, Petersen, Fitch and Pomeroy, 1945).

Very considerable variation in the degree of growth depression after thyroidectomy is apparent. Part of this is due to the regeneration of unremoved fragments of the gland (Marston and Peirce, 1932; Bullard and Andrews, 1943), and hyperactivity of the regenerated portion. When thyroidectomy is complete, the variation is largely due to the marked effect of age on the incidence of growth retardation. In the younger ruminant, growth depression is marked (Lanz, 1904; Simpson, 1923; Spielman *et al.*, 1945) while in the older animal such a depression is not so apparent. Growth is completely restored in these cretinous ruminants by thyroxine injection, thyroid feeding, or by feeding iodinated casein (Reineke and Turner, 1941; Brody and Frankenbach, 1942; Spielman *et al.*, 1945).

The pattern of growth depression in hypothyroidism is of interest, for there is considerable evidence of marked differential response in developmental pattern (Hammett 1929). In the hypothyroid lamb, the whole pattern of ossification is abnormal. Tooth eruption is delayed, upper jaw growth and frontal bone growth is defective while mandibular growth proceeds (Todd and Wharton, 1934). Long bone growth is retarded, and ossification of the epiphyses is impaired (Todd *et al.*, 1938). Wool growth per unit of surface area is reduced to 60 percent of normal in merino sheep, fibre diameter remains constant, and the production of "grease" is much reduced (Marston and Peirce, 1932). Meat production in these cretins is also impaired, for consequent upon the marked lethargy of the lambs there is an arrested development of musculature giving rise to a typical pot-bellied animal with marked muscular weakness (Liddell, 1926; Simpson, 1927a, b; Goldberg and Simpson, 1925). This is not a muscular degeneration but the retention of an infantile, unexercised muscle cell structure (Goldberg, 1927). In classical cases edema is found together with ascites (Goldberg and Simpson 1924). Marked deterioration of intelligence also occurs in these lambs (Liddell, 1921; Marston and Peirce, 1932). The net effect of these changes is an animal with the skeletal proportions and economic value of wild, unimproved stock (Schneider 1939).

Though the observations are not so complete, a similar morphological

pattern is shown in thyroidectomy of the young bovine. Spielman and his co-workers describe cattle thyroidectomized at ages of 13 and 15 months which showed no increase in sketelal growth, though increases in weight occurred. Their skin was dry and thickened; the hair dry and brittle; both animals showed edema and accumulation of synovial fluid at the hocks. Brody and Frankenbach describe a Jersey calf with abnormal bone growth about the pasterns and a disproportionate growth of the skull. In their animal, weight growth was depressed by 60 percent. Similar effects have also been described in experimental laboratory animals and in man. These have been reviewed by Koger and Turner (1943).

It is obvious that complete suppression of thyroid activity in the young ruminant is of little economic importance, though this can easily be accomplished by feeding goitrogenic agents (Turner, Reineke and Schultze, 1944; Schultze and Turner, 1945). Nevertheless, partial suppression of thyroid function in the young animal for short periods of time immediately before marketing might be of some value if the fat deposition in the carcass could be increased, thereby improving market quality. Experiments by Andrews and his coworkers (Andrews, Beeson, Barrick and Harper, 1947) on lambs, using thiourea and thiouracil, showed that increases in cod fat, internal fat and in carcass grade did in fact occur. These were not significant statistically. One major difficulty was unpalatability of the goitrogens. This was not the result of anorexia in the lamb due to incipient hypothyroidism (Marston and Peirce, 1932) but to the taste of the materials for it could be partially circumvented by salt admixture. In any case, growth reduction occurred at all levels of dosage, and no detectable feed efficiency differences were observed.

Partial suppression of thyroid activity in the older animal might also be of economic value. The logic of such a measure is that growth of muscle and bone is slower in maturity, and that the depression of the basal metabolism of the animal and depression of activity (Brody and Frankenbach, 1942; Spielman *et al.*, 1945; Andrews and Bullard, 1940) would result in more of the ingested net energy being available for deposition in the tissues as fat. In this respect it can be suggested that measures of efficiency of food utilization should be based on the gain of energy to the body rather than the gain in weight in order to make an accurate appraisal. Thiouracil-induced hypothyroidism in lactating rats is associated with cretinism in the sucklings (Hughes, 1944), for the mammary epithelium is permeable to thiouracil. If the same is true of the ruminant, attempts to fatten low yielding milk cows for sale and slaughter would not be feasible unless their milk were discarded and not used for either human or young animal consumption.

The possibility of increased fat gains in mild hypothyroidism has been ex-

plored by Andrews and his colleagues using the techniques of partial thyroidectomy and thiouracil feeding (Andrews and Bullard, 1940; Bullard and Andrews, 1943; Beeson, Andrews and Brown, 1947). Partial thyroidectomy of steers resulted in accelerated body weight gains for a period of 6–8 weeks. These gains were greatly complicated by the loss of weight and its subsequent recovery following the operation. Nevertheless the cattle were more docile and there was an improvement of the dressing percentage. The cumulative advantage was 0.2 lbs. per day gain in weight, but there was considerable individual variation, presumably due to the factors previously discussed. In experiments with thiouracil, unpalatability of these goitrogens which was obviously not due to hypothyroid anorexia was encountered. Despite an inhibition of thyroid function as evidenced by an increase in thyroid weight, there were but slight increases in weight gain, carcass quality or efficiency of food utilization, none of which could be judged significant on a statistical basis. Very promising preliminary results with thiouracil have also been noted in fattening beef cattle by Ensminger, Kline and Cunha (1946).

Prerequisite for the successful application of this type of compound are the determination of the dosage level required, the best method and frequency of administration and the age of animal and duration of treatment for which it will be the most effective.

Thiouracil is absorbed rapidly from the digestive tract and it is also eliminated rapidly, principally through the kidney. In studies with goats and calves, Ely, Olson and Reineke (1948) found that maximum concentrations of thiouracil were reached in blood plasma in 4 to 8 hours following oral administration. The drug was almost completely eliminated from the blood stream within 24 hours after cessation of administration; appreciable levels could be maintained continuously in the plasma by administration at 12 hour intervals. The dosage level and plasma concentration actually required to block thyroid function in the ruminant has not been fully determined, however.

The need for more basic investigations on this point is emphasized by the variability of response noted in three years of research with thiourea and thiouracil in feeder lambs (Barrick, Andrews, Beeson and Harper, 1948).

The limited data on induced hypothyroidism in the ruminant suggest that goitrogens could be used for short periods for younger animals to increase fat deposition prior to market and slaughter at a state of physiological immaturity, or possibly to increase fat deposition in older animals, when they might be used for longer periods of time. The data available suggest that such a usage might be feasible but the economic and practical future cannot be predicted. This largely depends on the relative financial regard for a carcass

carrying more fat and possibly slightly heavier. Until more is known of optimal dosages to be used, optimal length of thyroid depression; the sensitivity of the individual to a constant dose of goitrogen; possible agranulocytoses or other deleterious "side-effects" in the animals concerned (Beierwaltes and Sturgis, 1946) and lastly the palatability and suitability of the final products for human consumption, no definite recommendation can be made.

The Effect of Hyperthyroidism on Growth and Fattening in the Ruminant

In severe hyperthyroidism, when the basal metabolism is considerably elevated, marked losses of weight occur. This has been observed in the hyperthyroid ruminant and will be dealt with in the section on lactation. There is, however, the possibility that very mild hyperthyroidism in a young animal might accelerate growth. The literature on this aspect as it affects both animals and man has been reviewed by Koger and Turner (1943) and is nebulous and rather inconclusive. In mice thyroxine in minute doses increases growth rate fairly consistently (Robertson, 1928; Koger, Reineke and Turner, 1943; Koger, Hurst and Turner, 1942; Koger and Turner, 1943). In the experiments in Turner's laboratory, food intake was increased by 20–30 percent and the composition of the carcasses indicated a higher percent of protein but essentially the same energy content. This suggests, though does not prove, that the effect is an appetite stimulating one which more than compensates for the increased basal energy expenditure rather than a specific effect on N or mineral metabolism, or, to quote Braude (1947), " . . . the metabolic processes (are) speeded up in such a way as to cause the animals to eat more and thus grow faster." Nevertheless, changes in absorption rate from the gut (Althausen and Stockholm, 1938), rate of non-essential amino acid synthesis (Zitowskaya, 1939) or increased mitotic activity, especially in epiphyseal cartilage (Silberberg and Silberberg, 1940) may be more important factors.

Other than the beneficial effects of thyroid hormone on cretinous or myxedematous animals (see previous section) there is little information on the effect of mild hyperthyroidism on growth in ruminants.

No growth stimulation was noted in a group of 5 Hereford heifer calves started on 0.5 gm. iodinated casein at an average weight of 500 lbs. and continued on treatment for 185 days (Dinussen, Andrews and Beeson, 1948). Millen, Nevens and Gardner (1948) reported symptoms of extreme hyperthyroidism in 2 dairy calves receiving 4 gm. of iodinated casein per 100 lbs. body weight. Two calves given 1.3 gm. per 100 lbs. body weight showed a slight increase in growth above normal controls. By analogy with results obtained in swine (to be reviewed in a later section) it appears that any

experiment designed to test critically the possible effects of mild hyperthyroidism on growth in ruminants should be started at an early age—at least by weaning time if possible. Secondly, a graded range of dosages, from the *minimal effective* level up to one that will produce slight but discernible symptoms of hyperthyroidism should be inclued.

The Effect of Thyroid Secretion Status on Fertility of the Male Ruminant

Agreement on the role of the thyroid in male fertility is poor. A number of investigators hold the view that the thyroid has no direct effect on the testis, and that any reproductive disturbance in the male in hypothyroidism and hyperthyroidism is due, not primarily to endocrine imbalance but to changed metabolic status (Moore, 1939); changed nervous irritability (Lerman, 1942); general growth disturbances (Schneider, 1939) or to the complex inter-relations between the endocrine system and body metabolism as a whole (Cameron, 1945).

Thyroidectomy in the bull, resulting in complete clinical myxedema, leads to a disappearance of libido and interest in the estrual female (Petersen, Spielman, Pomeroy and Boyd, 1941). Spermatogenesis is not stopped for ejaculates obtained by massage of the ampullae are normal in sperm activity, morphology, longevity, and fertilizing ability. The administration of thyroid substance promptly and completely restores libido in the hypothyroid bull. The metabolic stimulant, dinitrophenol, has a similar effect, as does methyl testosterone (Petersen *et al.*, 1941). This suggests that the effect is largely one of lowered general metabolism rather than a specific endocrine one. Reineke (1946c) has fed iodinated casein to fourteen aged bulls, with favorable results, for ten of them showed considerably more vigor and more speedy ejaculation as a result. This supports the above contention, for it is well established that metabolism declines with advancing age (Brody, 1945). Schultz and Davis (1946) reported that iodinated casein increased the conception rate from 51.7 to 55.7 in five bulls out of seven, and resulted in spermatozoa with higher motility and greater resistance to low temperature (40° F.) storage. No change was noted in the percentage of abnormal sperm, and on the cessation of treatment (1.00 to 1.24 gm. iodinated casein/100 lbs. body weight daily) the conception rate remained higher than in the preliminary period.

The thyroid secretion apparently plays an important role in maintaining the normal pituitary—gonadal balance since the level of pituitary gonadotrophin is reduced in thyroidectomized goats (Reineke, Bergman and Turner, 1941). A further relationship is indicated by the fact that in male mice the response to gonadotropic hormone is reduced by thiouracil and augmented by feeding optimal levels of iodinated casein (Meites and

Chandrashaker, 1948). The directly opposite results obtained in rats is undoubtedly due to differences in hormone balances in the two species.

That thyroid hormone is capable of influencing directly the metabolism of semen is indicated by the work of Schultze and Davis (1947, 1948). Thyroxine added to bull semen in a critical concentration range caused an increase in oxygen consumption of samples having initial sperm counts above 800,000 per $mm.^3$, but had no effect in samples of lower concentration. Addition of thyroxine directly to semen was also reported to increase the conception rate.

In thyroidectomized rams, Berliner and Warbritton (1937) noted a fall in sperm number and an increase in the proportion of abnormal forms. The testes were edematous; there was a decrease in the interstitial tissues, and sloughing and pycnosis in the seminiferous tubules. In rams made hypothyroid with thiouracil, Bogart and Mayer (1946) noted a marked decline in sperm number, and motility, and an increase in abnormal forms. No specific observations were made on libido, but, as semen was collected with an artificial vagina, it appears that sex interest was not unduly impaired in these 40–50 day experiments. Berliner and Warbritton reversed the effect of thyroidectomy on sperm production by thyroxine injection, and Bogart and Mayer reversed the thiouracil effect by iodinated casein feeding. The latter workers, in confirmation of the earlier results of Berliner and Warbritton demonstrated that hyperthyroidism in the normal ram increased sperm production and decreased the percentage of abnormal forms during the summer months.

It should be noted that the greatest decline in summer fertility and the greatest response to thyroid therapy was observed in rams of the Shropshire breed. Warwick *et al.* (1948) reported that iodinated casein given to Hampshire rams (0.5 and 1.5 gm. daily) during April and May caused a deterioration in semen quality, particularly in rams that lost weight. During July and August the same treatment caused improvement. Negative results with regard to semen production were reported by Eaton *et al.* (1948) in mixed groups of Shropshire and Hampshire rams. Because of variations in age and also the fact that only two rams of each breed were involved in each group, however, this result does not seem conclusive. The question of the influence of thyroid status on reproduction assumes some practical importance in view of the temporary infertility of rams during hot weather (McKenzie and Berliner, 1937). "Summer infertility" has many points in common with hypothyroidism. Some of the symptoms are alleviated by thyroxine administration, though the low sperm motility and low semen volume, characteristic of the condition are not. It is postulated by Bogart and Mayer that the effect is due to the well-known relation between environmental temperature

and thyroid hormone secretion rate (Mills, 1918; Dempsey and Astwood, 1943), and that the thyroid gland is of direct importance in maintaining ram fertility. Whether "Summer infertility" is related not only to hypothyroidism but also to the well known effect of high scrotal temperature on spermatogenesis or to a lowered food intake and, consequently, low metabolism of the sheep during the summer (Lines and Peirce, 1931) remains to be determined.

It can be concluded, therefore, that in certain aged, and presumably hypothyroid, bulls small doses of iodinated casein cause a marked increase in libido, and may provide a method for prolonging the use of some prepotent bulls which otherwise could not be used. With regard to ram fertility the data are suggestive; however, experiments have not yet been reported that would determine the feasibility of prolonging the breeding season of sheep by such means.

The Effect of Thyroid Secretion Status on Fertility and Reproduction in the Female Ruminant

The thyroidectomized cow shows a complete absence of normal estrual behavior (Brody and Frankenbach, 1941; Spielman *et al.*, 1945). Ovulation and a normal ovarian cycle occurs and impregnation followed by normal pregnancy can ensue even in myxedematous animals. Iodinated casein, thyroid or dinitrophenol therapy results in normal sex interest in these cattle. The conclusion drawn by Petersen and his coworkers is that the thyroid is concerned with reproduction " . . . only indirectly, through maintenance of an optimum rate of metabolic processes."

Despite the fact that many hundreds of cows have been made hyperthyroid by iodinated protein feeding, no specific investigations on its effect on reproductive performance have been made. Blaxter (1945a) showed that cows came into heat under iodinated ardein therapy. It has been reported, however (Van Landingham, Hyatt, Weakley, and Henderson, 1947) that cows fed iodinated casein are slow to come into heat. At very high levels of stimulation disturbances in the psychic manifestations of estrus can be visualized, but no data are available on which to draw any conclusions as to possible effects on ovarian activity in either the cow or the small ruminant.

A point of considerable interest is the possible placental transmission of thyroid hormone. The bovine fetal thyroid elaborates its hormone at an early age. This will pass the placental barrier and relieve the symptoms of hypothyroidism in the completely thyroidectomized mother (Spielman *et al*, 1945). Similar results have been obtained in the goat, judging placental transmission of fetal thyroid hormone by growth resumption in the hypothyroid mother (Reineke and Turner, 1941). The important problem as to whether

the higher level of circulating thyroid hormone in the cow made hyperthyroid with iodinated protein can pass the placenta in the reverse direction, possibly reducing fetal thyroid size by an action on the fetal pituitary (see Van Dyke, 1939), has not been studied. There is some evidence (Tanberg, 1922) that the thyroid hormone of the mother retards the function of the fetal thyroid, for an earlier function of the fetal thyroid of the thyroidectomized goat occurs compared with the fetal thyroid of the normal goat. It is obvious that there is urgent need for study of this aspect of iodinated casein treatment of dairy cows.

Hypothyroidism in pregnant female rats induced by 6-methyl-2-thiouracil gives rise to a transitory thyroid hyperplasia in the young. When the young from such rats are fed to normal rats, thyroid hyperplasia occurs (Freissleben and Kjerulf-Jensen, 1946). It is thus evident that in this species transplacental transmission of goitrogens occurs. A similar transmission has been observed in the goat (Schultze and Turner, 1945) resulting in fetal thyroids ten times the normal size. The thyrotropic hormone of the anterior pituitary does not pass the placenta of the rat (Tobin, 1941).

The only conclusion which can be drawn as far as bovine fertility is concerned is that the need is for a greater knowledge of the effects of hyperthyroidism induced by iodinated casein on ovulation, implantation, the course of pregnancy and related phenomena and on the subsequent growth and development of the offspring.

The Effect of Thyroid Secretion Status on Mammary Growth and Lactation in the Ruminant.

Mammary Gland Growth. The effect of thyroidectomy on mammary gland growth in laboratory animals has recently been reviewed (Folley, 1940; Petersen, 1945).

Most of the workers who have thyroidectomized cows and goats agree that growth of the mammary gland occurs during an ensuing pregnancy. This is not unequivocal evidence of the absence of an appreciable effect of the thyroid on mammary gland growth, for, as pointed out in the previous section, there is a transfer of fetal thyroid hormone to the mother, and, in pregnancy the mother is no longer completely hypothyroid. Evidence comes from the attempts of Petersen and his coworkers (Petersen, Knodt, Ludwick, and Pomeroy, 1944) to produce mammary development in the thyroidectomized non-pregnant cow by estrogen administration. Diethylstilbestrol alone was without effect; there was no evidence of a classical synergistic action between stilbestrol and thyroxine administered simultaneously, and mammary growth occurred only when the symptoms of myxedema had been relieved. In the mouse (Mixner and Turner, 1942) the mammary growth

response to estrogen and progesterone was increased by the simultaneous administration of thyroxine.

Established Lactation. Thyroidectomy in the lactating goat has been reported by Grimmer (1918), Trautman (1919), Grimmer and Paul (1930), Grimmer and Wenzel (1933), Hibbs, Sutton and Kraus (1941) and others. The effect of goitrogens on lactation in the goat and cow has been reported by Schultze and Turner (1945). Thyroidectomy of the cow has been reported by Graham (1934) and by Spielman *et al.* (1944). In view of the difficulties attendant upon thyroidectomy operations (see section 1) and the possibility of a toxic depression of milk yield by thiourea administration, in no way related to induced hypothyroidism, agreement is good. Investigators are agreed that the hypothyroid state results in a depression, though not a cessation of milk production. In some cases it is difficult to distinguish the effect from that of a control operation (Graham, 1934a); in other cases milk production continues for protracted periods (Hibbs *et al.*, 1941). Complete thyroidectomy reduces yield by about 75 percent, partial thyroidectomy or limited periods of thiourea feeding results in a partial suppression.

The effect of thyroidectomy upon the composition of milk shows some variation among the reports of investigators. Grüter found the fat percentage of the milk of thyroidectomized goats was only 2.8 to 3.0—much lower than the controls (1930). Grimmer and Paul noticed a lowering of the fat percentage and subsequent recovery later in lactation, while the Minnesota workers found no significant change in fat percentage though a marked decline in fat yield occurred. Grimmer, and Grimmer and Paul have reported a decline in the lactose content of the milk and a fall in the non-protein nitrogen of the milk of goats after thyroidectomy. A depression of the Ca and P content of the milk has also been recorded by the German workers, (Grimmer, 1918; Grimmer and Paul, 1930; von Fellenberg and Grüter, 1932), the fall being greatest in the Ca content. This, however, slowly returns to normal and this recovery is not due to accessory thyroid tissue (Grimmer and Wenzel, 1933). Milk chloride increases.

An interesting relation between vitamin A and carotene has been reported in the thyroidectomized goa (von Fellenberg and Grüter, 1932; Fasold and Heidemann, 1933), and has recently been reviewed by Drill (1943). It is alleged that thyroidectomy in the goat results in an impairment of the conversion of carotene to vitamin A, resulting in an increase in the carotene content of the milk. In this respect Kaplansky and Balaba (1946) have reported that both iodinated casein and thyroglobulin catalyzed the conversion of carotene to vitamin A *in vivo*. Kon and his coworkers (1944–1945), on the other hand, have not been able to repeat the older German work. Both carotene and vitamin A in milk and blood remained unaffected

by either thyroidectomy or thiourea feeding. Allen, Wise and Jacobsen (1948) found no evidence of increased conversion of carotene to vitamin A in calves fed 1.5 to 3.0 gm. iodinated protein per 100 lbs. body weight. Smith *et al.* (1948) were not able to detect carotene in the blood of thyroidectomized and thiouracil treated goats. However, Barrick *et al.* (1948) stated that thiourea and thiouracil appeared to interfere with the conversion of carotene to vitamin A in feeder lambs.

The Effect of Induced Hyperthyroidism on Established Lactation with Special Reference to Iodinated Protein

It was shown by Graham (1934a, 1934b) that thyroid feeding or thyroxine injection increased both the milk and fat yield of dairy cows. This was confirmed by Jack and Bechdel (1935) by Folley and White (1936) and by others. In 1940, Turner reported preliminary experiments which indicated that the feeding of small amounts of iodinated protein would increase the milk production of lactating goats. The use of iodinated casein for stimulating lactation was also suggested by Folley and Bottomley (1940). Experiments on cattle were first reported by Reineke (1942), by Reineke and Turner (1942), by Blaxter (1943) and by Van Landingham, Henderson and Weakley (1944). Considerable data are now available on the effects of iodinated protein feeding on milk yield and composition. All these show that there is no difference between the effects of thyroxine administration and iodinated protein feeding as far as lactation is concerned.

There is a marked variability in the increase in milk yield obtained by feeding iodinated proteins or by thyroxine injection. A range of 0–38 percent has been reported for thyroxine (Hurst, 1940; Hurst, Reece and Bartlett, 1940), while in the case of iodinated casein a range of 0–50 percent has been recorded (Reineke, 1943; Archibald, 1945). For this variation there are a number of reasons as discussed in the sections below.

Dosage Response Relationships. Blaxter (1945b) used eight separate preparations of iodinated casein, iodinated blood protein and iodinated ardein in the earlier British studies. These varied markedly in their galactopoietic potency. There was, however, a marked linear relationship between thyroidal activity as judged by Xenopus tadpole assay and galactopoietic potency (Deansley and Parkes, 1945) but chemical estimation of the acid-insoluble iodine was not a satisfactory method of determining potency. Reineke *et al.* (1945) found good quantitative agreement between chemical determinations and thyroxine by a n-butanol extraction method and the results of metabolic assays in guinea pigs. Turner and Reineke (1946) have also found fair agreement between thyroxine content (butanol extractable iodine) and thyroidal potency as judged by an assay based on the weight

reducing effect in sheep. They conclude that while the biological activity of thyroprotein administered orally to ruminants will always be the final criterion of potency, the chemical method may prove of considerable value in the control and standardization of such preparations.

The response in milk yield to various doses of iodinated casein has been studied by Reineke, Herman, Turner and Ragsdale (1944) and by Blaxter (1943, 1945b). Using highly active preparations, Blaxter concluded that for doses of 15 gm. and 30 gm. daily, the dosage response curve of milk yield (as a percentage increase) was linear, the response being directly proportional to dose. Reineke and his coworkers found that at low doses (*circa* 5 gm. per cow daily) there was no increase in milk yield but only a slight but questionable increase in fat percentage. Ten to 15 gm. daily caused an increase in both milk yield and butterfat percentage. Higher dosages, ranging up to 80 gm. daily for a short period, caused a large initial rise in production, accompanied by tachycardia, elevated rectal temperatures and severe losses in body weight. Small responses to low doses (10 gm. daily) were reported by Reece (1944). Doses higher than 30 gm. have been given by Blaxter (1946) but not to a sufficient number of cows or for a sufficiently long time to provide accurate data. de Fremery (1936), however, injected 15 mg of thyroxine into a goat and found a decline in milk production associated with severe hyperthyroid symptoms. This is an enormous dose of thyroxine—probably equivalent to over 150 gm. of iodinated casein in the cow. It can be concluded that the dosage response curve in terms of milk yield is sigmoid. The ascending limb is short and, over a considerable range of dosage, the response is a direct proportionality only turning over when severe hyperthyroidism results.

Comparable data for thyroxine injections are not available, but it appears that 1 mg. of thyroxine injected is equivalent in the cow to 2.0 to 2.5 gm. of iodinated casein fed by mouth.

Physiological Status of the Cow. The age of the cow markedly influences her response to iodinated casein. Blaxter (1946) found in an experiment involving 1164 cows on 98 farms in England and Wales that the response in yield for heifers was 4.50 lbs., young cows, two or three times calved, 5.46 lbs., and old cows more than three times calved, 6.91 lbs. This age effect has been confirmed by Booth, Elvehjem and Hart (1947), and is understandable in view of the decline in metabolism with age (Brody. 1945). The body size of the cow also influences the response to a standard dose (20 gm. daily), the degree of stimulation being greater for the smaller animal (Blaxter, 1946). In this respect, there is no clear evidence on what basis dosage should be related to body weight, to assure a constant stimulation of metabolism. American workers have for the most part used a constant dosage per 100

lbs. body weight. Some evidence has been presented (Blaxter, 1948b) that, as between ruminant species, the dosage to give uniform increases in metabolism is related, not to body weight, but to the unit of reference of basal metabolism, namely body weight raised to the 0.734 power (Brody, 1945). This is logical, for the thyroid is concerned with basal energy expenditures, but whether it applies within a species is not known.

The breed of the cow has relatively little effect on the response. Blaxter has shown that cows when 20 weeks in milk and yielding 25 lbs. daily will give the following peak increase in daily milk production in response to 20 gm. iodinated casein daily: British Friesians 5.2 lbs., Dairy Shorthorns 5.9 lbs., Guernseys 6.2 lbs., Jerseys 6.4 lbs. and Ayrshires 6.8 lbs. Part of this is obviously a size effect, only a small part of the variation being due to true breed differences.

In his experiments with thyroxine, Graham observed that the cows with fine coats responded less well than those with course hides; dairy cows have much larger thyroids than beef cows (Krizenecky, 1932; Selehattin, 1930), while the thyrotrophic hormone content of the anterior pituitary of the dairy cow is higher than in the beef cow (Reece and Turner, 1937). It might be expected, therefore, that the response would be greater in the more sluggish, beefy cows than in essentially dairy cattle. This was not found by Blaxter (1946) nor was the response in dual purpose breeds—Red Polled cattle and Hereford crosses—larger than in the dairy breeds. The response was in fact smaller, though not significantly so on a statistical basis.

The most important factors influencing the response of the cow are her stage of lactation and producing ability. The Missouri group (Herman, Graham and Turner, 1938; Ralston, Cowsert, Ragsdale, Herman and Turner, 1940) found that the response to three daily injections of thyroxine at the peak of lactation was smaller than in the declining phase, and that the level of production of the cow was positively correlated with her response. This was confirmed for iodinated casein by Blaxter (1945b), who showed that the response was related to the "relative lactation stage," that is the percentage that milk yield prior to dosage had declined from the peak yield of the cow. The large scale British experiments show that one can predict the average response to 20 gm. of iodinated casein from the cow's yield and stage of lactation using the equation:

$$\text{Response in lbs./day} = 0.196\,(\text{No. of weeks cow has been milking}) + (0.120\,\text{daily yield in lbs.}) - 0.412$$

Poor cows in milk for 10 weeks and yielding 20 lbs. daily would increase by an average of 3.8 lbs. Good cows, in milk 30 weeks and yielding 30 lbs. daily, would increase by 9.1 lbs. on the average.

On the basis of the effect of age, weight, breed, body type, lactation stage and inherent productive capacity on the milk yield response, as well as the fact that the residual variance was small, Blaxter concluded that individual sensitivity to induced hyperthyroidism was not the sole or even a major reason for the large variation in response. Individual sensitivity to other effects of hyperthyroidism exist, for a very considerable variation in the ability of ruminants to withstand hyperthyroidism has been recorded. (Blaxter, 1948b.). A discussion of the reasons for the variation of the response with lactation stage and productivity is given in the reports of the British trials.

Length of Stimulation, Nutritional and Managerial Status, Climatic and Other Factors. The data reviewed in the previous two sections have mainly been experiments of short duration, in which treatment has been given for periods seldom longer than two months. Very few long term experiments have been reported (Reece, 1946, 1947; Thomas and Moore, 1948). The results of Hurst (1940) and of Reineke (1943) with a limited number of animals at low dosage levels indicate increases in yield persistency or retarded rate of fall of normal yield. The large scale experiments in Britain (at the 20 gm. dose level) show that a real reduction in response with continued administration not complicated by the lactation stage factors previously discussed, does in fact occur (Blaxter, 1945b). Under these conditions milk yields do not return to the normal level of the control cows when treatment stops. The depression is small—0.3 lbs. per day—and has been interpreted by Blaxter as meaning an increased rate of senescence of the mammary gland cells.

Thomas and Moore (1948), on the basis of the decline in production after iodinated casein feeding is stopped together with a decline in protein-bound plasma iodine, suggest that the thyroid gland may function subnormally for an extended period. Further research on this aspect of the problem is greatly needed.

The nutritional status of the animal markedly influences the response, especially in longer-term experiments (Moore, 1946; Moore and Sykes 1947; Hibbs and Krauss, 1947; Blaxter, 1946). Blaxter and Price (1945) showed that the pulse rate of the normal cow was closely related to her level of feed intake, a relationship already well-established for the steer (Ritzman and Benedict, 1938), and that in the normal cow, over short periods, there is a very high correlation of her milk yield with her pulse rate, due to changes in her level of nutrition and metabolism. They showed that the increase in milk yield that was associated with a one beat rise in pulse was the same, 0.3 to 0.4 lbs. per day, whether the increase in pulse rate was the result of feeding iodinated proteins or to a change in dietary level. In this

respect, Graham in 1934 found increases in yield when thyroidectomized cows were fed sugar and suggested that the relation of thyroid feeding to milk secretion was through its influence on total metabolism, both thyroid administration and sugar feeding increasing the metabolism of the cow. Moore and his associates (Sykes, Wrenn, Moore and Thomas, 1947, 1948) have dealt in more detail with this relationship of effect of feed intake and iodinated casein feeding and found that as far as heart rate is concerned, their effects are additive. This relation between heart rate and feeding level has not been confirmed by Booth, Elvehjem & Hart (1947). Moore (1946) has shown that if no extra food was given to cows fed iodinated casein a decline in the response occurred, which could be restored by an increase in food intake. Blaxter (1945a) had observed the decline in response under similar conditions, and in later trials additional food was given to prevent the loss of weight which occurs if no additional nutrients are supplied. Nevertheless, in large scale field trials, those farms on which the general level of nutrition was poor gave a very poor response. Thus, in herds of British Friesian cattle which were underfed, fed the normal British standards, and overfed, the responses of older cows was 4.1, 5.1 and 6.8 lbs./day respectively, each animal being given 20 gm. of iodinated casein incorporated in 4 lbs. of pelleted dairy feed (Blaxter, 1946). One interpretational difficulty arose, however, namely, that poor feeding was invariably associated with poor management—lack of attention to proper care and milking of the animals. It was concluded, therefore, that if factors limiting the normal production of the cow were present on a farm, whether due to poor management, poor nutrition, or disease then the response in milk production to iodinated casein would be poor.

Of considerable interest is a report on the feeding of an iodinated casein (Protamone) feed mixture to commercial herds in the Los Angeles milk shed (Graham, 1948). Records were reported on 480 cows during a 12-week hormone feeding period. Extra nutrients were provided by mixing the daily hormone dosage in 2 lbs. of feed and providing this in addition to the regular ration. The maximum rise in production, amounting to approximately 5 lbs. of milk and 0.3 lb. of butterfat daily, occurred during the 4th week of hormone feeding. High production was maintained for 9 weeks followed by a decline at approximately the normal percentage rate. The culling rate was considerably lower in the hormone fed than in normally fed cows because production was maintained above the 30 lb. culling level for a longer period. From mathematical considerations of the lactation curve it was recommended that hormone-fed cows be culled at 5 lbs. higher daily production in order to maintain the maximum herd average.

Lower nutritional plane may be one of the factors concerned in the report

of low response in the summer months (Ralston *et al.*, 1940; Booth *et al.*, 1947), though no differences have been reported in specific experiments to this effect in Britain (Blaxter, 1945b). In this regard, the milk responses of cattle in Louisiana in the hot summer months (Seath, Branton and Groth, 1944, 1945) do not differ markedly from those in colder climates.

The Effect on Milk Composition. The fat percentage of the milk increases when iodinated protein is given or the cow is made hyperthyroid in other ways. Low doses, in fact, increase the fat percentage without affecting yield to any appreciable extent (Reineke *et al.*, 1944). This means that where milk yield is increased by 5–20 percent, fat yield is increased 25–50 percent, the fat percentage increasing by as much as 2.0 percentage units (Van Landingham *et al.*, 1944). There is some indication that cows with low fat percentage show the greatest response (Blaxter, 1945b). When iodinated protein administration was stopped a transient increase in the fat percentage was observed by Blaxter, and this has been shown to be an under-feeding phenomenon (Hibbs and Krauss, 1947), comparable to the well-known effect of inanition on the fat percentage. Where long term stimulation is carried out, there is no indication of a decline in the response in fat percentage (Reece, 1946, 1947). The contrary results of Archibald (1945) are complicated by reduction of the dosage in the latter part of the experiment concerned. Thomas, Moore and Sykes (1948) reported that the fat percentage in the milk of thyroprotein-fed cows was increased above that of normally fed cows for only 30 to 40 days. Blaxter's data indicate that the dosage response curve for fat yield is linear over a considerable range, but the causes of the marked variation in total fat yield have not been studied in such detail as those causing variation in milk yield. Studies with small numbers of cows, however, indicate that, as far as lactation stage and productivity factors are concerned, a close relationship between responses in milk and fat yield exists (Ralston *et al.*, 1940; Blaxter, 1945b).

The character of the milk fat is unchanged in hyperthyroidism (Smith and Dastur, 1940; Hilditch and Paul, 1936). There is, however, a tendency for a rise in the unsaturated fatty acids and a fall in the saturated acids to occur in the first few days of stimulation. The changes in the blood lipids is very comparable to the changes during inanition in the cow, for corpuscular lipid remains unchanged, plasma lipid falls markedly, while the general nature of both corpuscular and plasma lipid remains relatively stable (Smith and Dastur, 1940).

The solids-not-fat content of the milk increases during hyperthyroidism (Folley and White, 1936). Variable reports on the magnitude of such a change have been shown due to errors of calculation by failing to take into account concomitant changes in fat percentage (Blaxter, 1945a). There is an

increase in the percentage of lactose (Jones, 1935; Folley and White, 1936; Ralston *et al.*, 1940; Smith and Dastur, 1940); this has not been confirmed by Archibald (1945) who found by different calculations that a decrease occurred. The increase observed by most workers is from 5–10 percent, and thus the total lactose yield is considerably increased. The blood sugar increases by 10–20 percent.

All evidence suggests that a decline in milk protein occurs. First, a decrease in blood and plasma total nitrogen occurs (Ralston *et al.*, 1940; Booth *et al.*, 1947). Amino N shows no change (Jones, 1935), but urea N falls by some 20–40 percent (Booth *et al.*, 1947). Detailed studies of the plasma protein fractions have not been made, but, in the hyperthyroid human, albumin is consistently low. (Lewis and McCullagh, 1944). The Missouri workers and those in Britain (Ralston *et al.*, 1940; Smith and Dastur, 1940) have reported declines in the N content or the protein content of the milk of hyperthyroid cows. Archibald (1945) found a marked decrease in the casein content and parallel increases in the globulin+albumin fraction when cows were fed iodinated casein. This has been confirmed by Booth and his coworkers (1947) who also noted a severe drop in urea N in the milk. Van Landingham and his associates, however, report that no change in total N, casein N or non-casein N occurs on feeding iodinated casein (Van Landingham, Hyatt and Weakley, 1946). No change in milk protein was found by Hibbs and Krauss (1946, 1947).

It can be concluded, therefore, that there is an increase in the lactose content of the milk and possibly small decreases in the protein and non-protein nitrogen content on feeding iodinated casein. The net effect is a small increase in the solids-not-fat content. There is no evidence available of change in the inorganic constituents.

Comparatively little work has been carried out on the effect of hyperthyroidism on the vitamin content of milk. In the British experiments Thompson determined the effect of thyroxine injection and of feeding iodinated casein, ardein and blood protein on the vitamin A, carotene, ascorbic acid, total and free thiamin and riboflavin content of the milk.

The few investigations show that the carotene of the milk is not affected (Thompson, 1946; Hibbs and Krauss, 1946, 1947; Kemmerer, Bolomey, Vavich and Davis, 1946). While Kemmerer and his associates found no change in the vitamin A content of milk, Hibbs and Krauss report frequent decreases in milk and plasma vitamin A, sufficient for them to suggest that continued therapy might result in vitamin A deficiency. Iodinated casein (1.5 gm./100 lbs. body weight) had little effect on carotene and vitamin A levels of calves receiving ample carotene from alfalfa hay. At marginal levels of carotene intake (2500–3000 I.U. per 100 lbs. body weight) there was

depression of both substances in the blood (Allen, Wise and Jacobson, 1948). No other data are available on the changes in the content of fat soluble vitamins in milk.

The vitamin C content was reported to decline by some 30 percent when cows are fed iodinated proteins (Van Landingham, Henderson and Weakley, 1944; Thompson, 1946; Booth *et al.*, 1947). Hibbs and Krauss, however, found no change in this respect in either plasma or milk. Thompson has shown that when thyroxine is injected, an increase in milk ascorbic acid concentration occurs so that the total yield of ascorbic acid was increased by 50 percent. It was only when iodinated proteins were fed that a depression of both concentration and total yield of ascorbic acid occurred. The depression of the ascorbic acid content of the milk is thus due to the effect of the large quantity of iodine ingested and can be produced merely by feeding potassium iodide (Brown, Van Landingham and Weakley, 1941). The depression caused by feeding iodinated casein cannot be stopped by injecting vitamin C (Booth *et al.*, 1947).

The thiamine content of the milk has been reported as unchanged or decreased (Kemmerer *et al.*, 1946; Hibbs and Krauss 1947). Thompson estimated both free thiamine and the total thiamine after enzymatic hydrolysis had liberated the protein bound thiamine and dephosphoryated the thiamine pyrophosphate. Total thiamine remained unchanged in hyperthyroidism, but the free thiamine decreased in every case. This was thought due to changes in the alkaline phosphomonoesterase titre of the milk. It has been shown in both the normal cow and sow that the ratio of free to total thiamine increases as lactation advances and is in proportion to the parallel increase in the phosphatase activity of the milk. In early lactation, the enzyme titre is low and the bound—presumably phosphorylated—thiamine correspondingly high. (Houston, Kane and Thompson, 1940; Braude, Coates, Henry and Kon, 1947). It was first shown by Folley and White (1936) that the phosphatase of the milk decreases markedly in hyperthyroidism, while that of the blood increases. This was confirmed by Blaxter (1945a) for iodinated protein stimulation, on the same cows as used in Thompson's study. Thompson's conclusion that iodinated protein or thyroxine therapy affects the ratio free/total thiamine, by alteration of the enzyme titre is thus of considerable interest.

Riboflavin has been reported to be decreased by Kemmerer and his coworkers. Little change was found by Thompson, while Hibbs and Krauss have suggested that a decrease in riboflavin concentration only occurs under iodinated casein stimulation if the plane of nutrition of the cow is low. Nicotinic acid increases in concentration under iodinated casein stimulation (Kemmerer *et al.*, 1946). No data are available on the effects of iodinated casein on other members of the B-complex in milk.

The Permeability of the Mammary Epithelium to Thyroid Hormone. The data on this aspect of the iodinated casein treatment of cattle have recently been reviewed in detail by Robertson (1945). The experiments on laboratory animals and, more important on humans, especially children show conclusively that the thyroid hormone does not pass the mammary epithelium (Reineke and Turner, 1944; Robertson 1945; Bruger and Silberbush, 1946; Hurst and Turner, 1948).

As far as milk composition is concerned, the milk produced by cows receiving iodinated casein is perfectly safe, and nutritionally adequate. The fall in vitamin C content is not of great importance as far as human consumption is concerned, for milk is not a major source of the ascorbic acid needed by the human.

The Metabolic and Physiological Effects of Severe Hyperthyroidism on the Lactating Cow. It is well known that thyroidal stimulation will increase the metabolic rate. Obviously a higher level of nutrient intake will be required to support the elevated metabolism. Whether or not any net gain will occur from the increased production will depend on the distribution of the extra nutrients between the requirements for extra milk production and the increased metabolic expenditure. As pointed out by Schneider (1939), low levels of thyroidal stimulation are usually observed to produce anabolic effects; with higher dosages, catabolic effects predominate. In line with this principle it would be expected that the effect obtained will be determined in large part by the balance between the dosage of iodinated casein and extra nutrients given, and further that the dosage must be limited to a critical range for optimal results.

Many of the investigations reported to date have been conducted at dosage levels that produce a serious condition of hyperthyroidism in the cow. While such a condition can be tolerated for short periods without serious injury, there is a growing recognition of the importance of administering the iodinated protein at the minimum effective dosage level, particularly in long term trials (Reineke *et al.*, 1944; Reece, 1947*a*, *b*; Swanson and Knodt, 1948).

No specific investigation has yet been made on the extent of the increase in the basal metabolic rate of the cow at various levels of dosage, though in Denmark increases in total heat production on feed of 30 percent have been observed on feeding 25 gm. of iodinated casein (Thorbeck, Hansen and Moustgaard 1948). Indirect evidence shows, however, that a dose of 20 gm. daily would increase the basal metabolic rate by 25–30 percent, while studies with sheep have shown that the increase in basal metabolism, like the increase in milk yield is directly proportional to dosage/Kg. W. 0.73 (Blaxter, 1948c).

There is no evidence that the utilization of metabolizable energy is im-

paired or altered during hyperthyroidism (Klein, 1931). In the sheep given heavy dosages of iodinated casein, however, the apparent digestibility of the ration falls, associated with an increase in the water content of the feces, and probably due to increased peristalsis of the gut (Blaxter, 1948a). In this respect some 7.7 percent of the cattle treated in England showed scouring or digestive disturbances compared with 1.7 percent in the controls. This was a highly significant difference statistically.

As would be expected, the nitrogen metabolism of the cow is increased with high doses of thyroxine (Owen, 1946) or iodinated casein (Thorbeck *et al.*, 1948). This is also true of the sheep given comparable doses and the N distribution of the urine of sheep fed iodinated casein (4, 6, 8 and 12 gm. daily) shows a marked increase in purine catabolism and a deamination of body protein for energy purposes (Blaxter, 1948a). Whether the negative N and energy at these high dosage levels can be restored to normal by additional food is not known except indirectly. The loss of weight of hyperthyroid cows—which can amount to 100–150 lbs. (10–15 percent) in a few weeks (Seath *et al.*, 1944, 1945; Blaxter, 1945a) can be partially or wholly prevented by giving additional food, the actual result being determined by the balance between the metabolism and the extra nutrients supplied. In the British experiments in which additional food was given 23.4 percent of the cows still lost weight, and it was the smaller cattle, receiving the largest dosage relative to their size, which lost the most (Blaxter, 1946). The Beltsville workers (Thomas *et al.*, 1948) have shown that cows receiving 15 gm. iodinated casein daily on a ration supplying nutrients at 125 percent of requirement show normal body weight changes as well as a sustained increase in milk production.

Pulse rate increases, the increase being proportionally greater at high dosages than at low, presumably because cardiac output is augmented at low dosages by means other than an increased rate of contraction (Blaxter, 1945b). Pulse rates well over 100 per minute have been recorded in cows given 30 gm. of iodinated casein, and in sheep the equivalent of a dose of 70 gm. in the cow increases pulse rate to 150–200 per minute (Blaxter, 1948b). Changes believed to indicate heart damage have been recorded in electrocardiographic studies of lactating goats injected with thryoxine (Ralston *et al.*, 1940). Damage was not reported in concomitant studies in cows, but these were made after but three injections. Extra systolic contractions, marked cardiac arrhythmia, and auricular fibrillation have been recorded in cows in the British experiments, a relatively high and statistically significant incidence occurring. In sheep similar abnormalities have been noted on auscultation, and death due to hyperthyroidism in this animal has been found to be associated with valvular lesions, hypertrophy of the right heart,

degeneration of ventricular muscle tone, as well as with a respiratory involvement (Blaxter, 1948b). In this regard it might be added that the hyperthyroid heart becomes less sensitive to vagal stimulation and markedly sensitive to adrenalin (Hoffman, Hoffman and Talesnic, 1947). At lower dosage levels (1 and 2 gm. daily) the heart action of the thyroidectomized sheep was restored to normal, but no electrocardiogram changes indicative of heart damage were observed (Mullick *et al.*, 1948). Even though the heart rate was increased 40 to 50 percent in cows receiving 25 gm. iodinated protein daily for a 90 day period (Thorbeck, Hansen and Moustgaard, 1948), electrocardiogram studies did not indicate abnormalities in heart function.

The cow is, to all intents, a non-sweating animal, and a large part of her loss of heat at high temperatures is by way of the latent heat of water vapor in expired saturated air. Her increased heat production under iodinated casein therapy is thus reflected in an increased respiratory frequency. As environmental temperature rises, the percentage of her total heat lost by vaporization increases too, and this accounts for the fact that the increase in respiratory frequency is so much greater at high temperatures (Seath *et al.*, 1944, 1945; Blaxter, 1945a). As shown by Regan and Richardson (1938), at high temperatures in the normal cow, increases in body temperature and a compensatory anorexia occurs. The same occurs in the hyperthyroid cow but at lower temperatures. In severely hyperthyroid sheep, the augmented respiratory rate is associated with paroxysmal coughing leading to emphysema and lung edema (Blaxter, 1948b). Under conditions where normal cattle have difficulty in heat disposal 15 gm. of iodinated casein daily produces serious effects (Seath *et al.*, 1945; Gardner and Millen, 1948). The thyroid function of rats (Dempsey and Astwood, 1943), mice (Hurst and Turner, 1948) and chicks (Reineke and Turner, 1945b) is depressed during periods of high temperature. If, as seems likely, the same thing is true of cattle it could be expected that they would be more responsive to thyroidal stimulation and also that stimulation would be observed at lower dosage levels in hot than in cool weather. However, the minimal dosage necessary to elicit a milk production response under these conditions has not been determined.

Owen (1946) has shown that the cow is forced into negative Ca balance by large thyroxine injections. The importance of this observation in view of the annual cycle of mineral metabolism in the cow can readily be visualized. Blaxter, in sheep experiments, has shown an acceleration of both Ca and P metabolism on feeding iodinated casein (4 to 12 gm. daily) and has indicated that it is possible to remove 10 percent of the total Ca of the body in a three-week period of extreme hyperthyroidism (1948a). Blood levels of Ca and Mg are not affected in either the cow or the sheep while

the blood inorganic P only increases if hyperthyroid anorexia occurs.

The smallest dosage of iodinated casein given in this work is at least four times the amount required to cause perceptible stimulation in the sheep, as indicated by the results of Mullick *et al.*, (1948), Warwick *et al.* (1948) and Eaton *et al.* (1948). No data on the nitrogen or mineral balances in ruminants at dosages within a practical range of stimulation that will be tolerated for extended periods have thus far been reported. There is some evidence that in growing animals (Koger and Turner, 1943) mild hyperthyroidism is conducive to increased storage of both nigroten and minerals. In view of the delicate balance between the anabolic and catabolic functions of thyroid hormone and the importance of the dosage in determining which will predominate there is a need for metabolic studies at dosages within the range of physiologic tolerance before general conclusions can be drawn.

Exophthalmos, with an increased palpebral fissure has been observed in cattle given 20 gm. of iodinated casein daily, but not in sheep (Blaxter, 1945a, b, 1948b). Premature shedding of the winter coat has been noted (Blaxter, 1946). Muscular tremors, nervousness, fatigue, hyperirritability and other symptoms of Graves' disease have all been recorded in the cow.

Some cows appear more susceptible to hyperthyroidism than others, as far as clinical manifestations form a basis of judgment. This accounts for the fact that in a number of experiments the treatment of an animal has been stopped or dosage reduced prior to the projected termination of the trial. That this variation applies to the lethal dose of iodinated casein for the sheep is shown in Blaxter's experiments (1945b). One out of two sheep died after receiving 6 gm. of iodinated casein daily while one survived after receiving 12 gm. for the same period of time. Transferred, on the basis of metabolic body size relationships, death in the cow could be expected at dosages only 2–3 times those which have been used in many investigations, namely 15–20 gm. daily. The fact that on two out of 98 farms in the British experiments over-dosage of all the experimental animals occurred, despite considerable precautions, makes this aspect of iodinated casein stimulation an extremely important one.

There is no evidence on the effect of hyperthyroidism on life span. Short term trials, however, do not indicate any increase in the incidence of contagious disease (Blaxter, 1946).

An Appraisal of the Practical Use of Iodinated Protein Preparations for Increasing Milk Production. To appraise the use of iodinated proteins in farm practice, a clear concept of the place it can take in established modes of production must first prevail. In England the objective has been to increase milk yields during short periods of the winter months in herds breeding their own replacement stock. This means that, as an autumn

calving program is in operation, cows can be treated at the optimal time, and the growth of spring grass will then partially prevent the fall in production when treatment stops. It has been shown in field trials that this severe fall can be prevented too, by a gradual reduction in the amount of iodinated protein fed. In Scotland a similar short-term stimulation has been visualized in which spring-calving cows can be treated in late summer prior to a growth of autumn grass. In the United States where modes of production are so diverse, many modifications of this method of feeding iodinated protein can be visualized, while in commercial herds a scheme of longer-term stimulation might be possible. With the primary concept of its integration in established practice in mind, four further factors must be considered; first, whether the milk produced is safe for human consumption; secondly, whether its use would be economically sound on the basis of immediate financial return; thirdly, whether its use would possibly result in undesirable effects on the cattle population, and lastly, whether its use is to be preferred to other methods of increasing the total production of milk and fat by the industry.

The first two points are readily answered. The milk is safe and nutritionally suitable for human consumption, and if the price of iodinated casein will be similar to the tentative estimates that have been made, then, taking into account the additional food required the process would be economically justified.

With regard to possible undesirable effects it is well established that excessive dosages of iodinated protein will produce serious metabolic disturbances in the cow. In any plan of treatment it would be imperative not only that the dosage be kept within the physiological tolerance limits of the cow, but also that sufficient nutrients be supplied to support both the increased production and increased metabolic rate. In this regard a great deal of research is still needed on the relation between iodinated protein dosage and nutritive requirements for essential minerals and vitamins, as well as for energy, on a scale extending from the minimum effective dosage level up to the point of excessive stimulation. The inability of cows to withstand iodinated casein under hot climatic conditions at dosages that are well tolerated in a cooler environment seems well established. It would be of considerable interest, however, to investigate further the modifying effect of high temperatures on the response to lower dosage levels.

No information is yet available on the effects of iodinated protein on the herd life of the cow or on general health and breeding efficiency. However, no clear cut cases of reproductive difficulties have been noted in the rather extensive investigations reported thus far. An assessment of the long term effects must await the results of investigations conducted with adequate numbers of cows over a period of several years. As pointed out by Hyatt

and Henderson (1948), commercial dairies may find the use of iodinated casein profitable at the present time, but many questions should still be answered before it is used to any extent in purebred breeding stock.

Lastly, the information available suggests that on farms where there is poor control of disease, poor management and poor nutrition of the cattle, the response is less than 60 percent of the response where these conditions are good. Furthermore, it is only the really high producing cattle—the better bred cattle—which give maximal responses. On farms with poor cattle and with poor technique in milk production, increases in milk yield could better be attained by greater attention to the breeding, feeding and care of the stock than by iodinated protein stimulation.

The Alteration of Thyroid Secretion Status in Swine

In the normal pig, there is an enormous variation in thyroid size but the studies of Zorn, Bruggemann and Moldrick (1939) have shown that there is no relation between thyroid size or iodine content and either the food requirement for growth or the ratio of fat to lean in the carcass. Nevertheless, the small amount of data available on experimental alteration of thyroid secretion status indicates that growth can be markedly affected.

Influence of Hypothyroidism in Swine. Complete thyroidectomy of the young animal results in a pot-bellied, dull, lethargic, mentally stupid and undersized animal comparable to the cretin sheep previously described (Caylor and Schlotthauer, 1926). In the older animal, growth is also retarded and myxedematous symptoms occur. These pigs are more susceptible to disease and the myxedema is alleged not to occur when protein-low diets are fed (Schlotthauer and Caylor, 1929). Partial thyroidectomy by removal of only the main lobes of the gland does not induce cretinism, and though there is no apparent change in physical appearance, reproduction and resistance to infection is impaired (Palmer, 1917).

Thyroidectomy of pigs has been advocated and practiced as a means of increasing fat deposition (Zorn and Bruggeman, 1939; Duerst, 1941). The effect of thiouracil on weight gains and feed utilization was first reported by Muhrer and Hogan (1945). In paired feeding experiments lasting 28 days the rate of gain increased from 1.4 to 2.1 lbs. per day, while the food required per lb. of gain decreased from 4.82 to 3.10 lbs. Growth of the pigs was retarded; they were wider and shorter and appeared fatter than controls. Subsequent work (Muhrer, Warner, Palmer and Hogan, 1947) showed a slight decrease of the fat percentage of the carcass, but a slight increase in water content.

The paired feeding method tends to exaggerate the advantages to be obtained with thiouracil since the food intake of the controls is held to that

of the thiouracil treated animals, and the latter have their appetites depressed somewhat by the inhibition of thyroid function. Nevertheless a considerable improvement in economy of gains is also obtained with *ad libitum* feeding. In Crossbred, Chester White and Yorkshire pigs fed 0.1 percent thiouracil for 41 days at the end of the fattening period the feed required per unit gain was reduced 8.4, 13.8 and 18.8 percent, respectively in the three types of pigs even though the daily rate of gain was reduced slightly in each case (McMillen, *et al.*, 1946, 1947). Carcass measurements failed to reveal any significant differences between the experimental and control pigs. Small, but insignificant reductions in skeletal measurements indicated that thiouracil may have caused a slight reduction in growth. Muhrer *et al.* (1947) observed a 24.4 percent reduction in the feed required per unit gain in an *ad libitum* trial in which 0.1 percent thiouracil was fed. Vander Noot, Reece and Skelly (1947) reported that thiouracil (0.25 percent) given in *ad libitum* trials resulted not only in a 27.5 percent increase in economy of gains, but also an increase in rate of gains. In a second paper (1948) the same authors reported improved economy but a reduced rate of gain. The results of thiouracil administration both by paired feeding and *ad libitum* methods have been fully confirmed in a detailed study by Terrill, Krider, Carroll and Hamilton (1948). In paired feeding trials thiouracil-fed pigs gained more rapidly and in *ad libitum* trials they gained less rapidly than the controls. In all cases the economy of gains was improved. The importance of correct timing in this type of procedure is illustrated by the fact that a significant decrease in rate of gains occurred during the last 2 weeks of the 6-week period on thiouracil. From the results of these trials as well as those of Hale, Robertson, Lyman and Wyatt (1948) it appears that optimum results would be obtained with 0.15 percent thiouracil in the feed given during the final four weeks of the fattening period.

As would be expected, thiouracil given at too early an age (Willman *et al.* 1946; Beeson *et al.*, 1947; Vander Noot *et al.*, 1948) results in greatly reduced gains accompanied by symptoms of cretinism or myxedema. The reason for the extreme growth depression observed by Avecedo *et al.* (1948) in pigs fed 0.25 percent thiouracil is not readily apparent. However, as suggested by these authors, the breeds of pigs employed, the extended feeding period of 51 days or an excessive dosage of thiouracil for the prevailing climatic conditions may be contributing factors.

The increased economy of gains usually observed with thiouracil is readily explained by the lowered heat production. In energy balance studies with rats (Bratzler, Barnes and Swift, 1948) it was clearly shown that in thiouracil-fed animals metabolizing the same amount of food as normal controls, less energy is lost as heat.

Effect of Hyperthyroidism in Swine

In experiments involving hyperthyroidism in growing pigs both the age at which the treatment is started and the dosage level of active substance administered are extremely important factors. In Denmark, Jespersen (1941) fed fresh thyroid to pigs. The dosage was apparently excessive since the rate of gain was halved and the amount of food required per lb. gain was doubled. Using small dosages of iodinated casein (0.005–0.006 percent of the ration) fed to Berkshire pigs starting at weaning time, Reineke and McMillen (1946) reported a significant increase in the rate of gain and a slight increase in efficiency of food utilization. In further experiments (Wallach *et al.*, 1947; Reineke, McMillen and Bratzler, 1948) Yorkshires and Duroc Jerseys receiving 0.006 percent iodinated casein in their ration gained 15.1 and 11.3 lbs. more per pig than their controls in a 112 day feeding trial. Berkshires fed 0.012 percent iodinated casein for 98 days and 0.006 per cent for 14 days exceeded the gains of their controls by 27.0 lbs. per pig. In all cases the economy of gains was improved slightly, but the statistical significance of this could not be determined because group feeding methods were used. This rather surprising indication of increased overall efficiency is accounted for by the fact that the pigs need to be maintained for a shorter time because of their increased rate of gain. Decreased feed efficiency with no improvement in gains was observed in an inbred strain of Chester Whites. The more mature, thicker and meatier conformation described for the first three breeds is diametrically opposed to the photographs published by Jespersen. When slaughtered at the same weight as the controls (but a week to 10 days younger) no significant differences were found in the carcass measurements although the experimental pigs looked thicker and shorter legged on foot.

Similar results were reported by Beeson, Andrews, Witz and Perry (1947) with pigs of the Duroc Jersey breed. Iodinated casein fed as 0.0044 percent of the ration was without effect but pigs receiving 0.0088 percent for 84 days gained 26 lbs. more per pig with 10 percent less feed required per unit gain. A significant increase in body length and weight of bellies and picnic shoulders was reported. In pigs started on experiment at an average weight of 40 lbs. and continued for 104 days 0.0088 percent iodinated casein was without effect, but 0.0132 percent caused a significant increase in gain and also resulted in significantly longer carcasses with heavier loins (Perry *et al.*, 1948).

It is noteworthy that in all of the trials in which positive growth responses were observed, iodinated protein was given as a very small percentage of the ration and started at an early age. Perceptible stimulation of the growth rate did not occur until six weeks to two months of treatment. As would

be expected, no growth stimulation was found in pigs placed on iodinated casein for a short time during the fattening period (Muhrer, Warner, Palmer and Hogan, 1947).

In England, Braude (1947) carried out seven experiments with Large White pigs using *ad libitum* feeding methods. Starting with high dosages of 1.5 gm. daily he observed heavy respiratory rates, hyperirritability, and a retarded rate of gain. As the dosage was lowered, at no time could a statistically significant acceleration of growth be demonstrated. It should be noted, however, that Braude administered a constant dosage to growing pigs regardless of their increasing body weight. The negative results of Vander Noot, Reece and Skelly (1948) can probably also be accounted for by differences in experimental conditions.

There have been only two brief reports, involving five sows, on the effect of iodinated casein on lactation and growth of suckling pigs (Reineke and McMillen, 1946, Braude, 1947). On the basis of the work on the ruminant such a stimulation may be possible, but the data available are not sufficient to warrant any conclusion as to its practicability.

Although practical recommendations are hardly warranted at this time, the modification of thyroid function shows considerable promise for application in swine husbandry. Its proper use, however, will require intelligent consideration of the principles of thyroid physiology involved. Iodinated protein will be effective in stimulating growth only if given during the early growth stages when the requirement for thyroid hormone relative to body weight is at a maximum (Reineke, McMillen and Bratzler, 1948; Hurst and Turner, 1948) and at dosages within the range of physiological tolerance. Thiouracil, on the other hand, will stop growth by blocking out the needed hormone function if given at too early an age. If given during the last 4 to 6 weeks of the fattening period, however, it will usually result in a substantial improvement in economy of gains with little decrease in rate of gain. Considerable research is still needed with both drugs to determine the possible modifying effects on the response of such factors as breed and strain of pigs, nutritional adequacy of the ration, season of the year and general environmental conditions.

Modification of Thyroid Secretion Status in Poultry

Considerable work has been carried out on the effect of modification of thyroid secretion status in poultry. A great deal of the pertinent literature is concerned with the effects on plumage type, feather pigmentation, feather structure and feather growth in both male and female birds, as well as the thyroid-gonad relationship. This literature has been reviewed recently by Blivaiss (1947) and by Fleischmann (1947) and its presentation is beyond

the scope of this review. Only the practical aspects of hypothyroidism and hyperthyroidism will be discussed.

Modification of Growth and Fattening Processes

The object of most experiments in which iodinated proteins and goitrogens have been given to poultry has been to accelerate the growth of young birds and to enhance body gains of fat during the period prior to slaughter. Thyroid feeding of older poultry has resulted in growth depression (Crew and Huxley, 1923). Parker (1943) and Irwin, Reineke and Turner (1943) have reported that feeding iodinated casein will accelerate the growth of chicks to a limited extent providing dosage is low. Feather growth is markedly increased, in agreement with the earlier investigators (see Blivaiss, 1947). These results have been extended by Turner, Irwin and Reineke (1944) who found a slight growth depression with 0.1 percent of iodinated casein in the diet together with a decrease in subcutaneous fat. Four weeks were acquired to restore the subcutaneous fat after withdrawal of iodinated protein from the ration.

At a lower dosage level (10 gm. per 100 lbs. feed), Wheeler, Hoffman and Graham (1948) reported a significant increase in body weight of Rhode Island Red males, but not in females at 12 weeks of age. There was a highly significant increase in uniformity of the male birds and no significant difference from the controls in percentage of abdominal fat. Similarly, Quisenberry and Krueger (1948) reported that in 800 chicks of the New Hampshire and White Plymouth Rock breeds fed iodinated casein to six weeks of age both the rate of gain and efficiency of feed utilization was improved.

Rapid-growing strains of Barred Plymouth Rock and New Hampshire Red chickens were reported (Glazener and Shaffner, 1948) to have higher thyroid activity than slow-growing strains. Conversely, the slow-growing Plymouth Rocks showed a greater growth response to iodinated casein than the rapid-growing strain.

While results on growth have been variable, all of the reports to date have been consistent in showing a significant increase in early feathering of chicks fed iodinated casein. Contrary to expectations, no significant difference was found in the thyroid secretion rate of fast- and slow-feathering Rhode Island Reds (Boone, Reineke and Davidson, 1947). Even so the slow-feathering strain showed a highly significant increase in feathering, but not in growth, when fed iodinated casein at levels of 0.04 percent or above. Iodinated protein has also been used in relatively high dosage to induce forced early molting in turkeys (Kosin and Wakely, 1948). The forced molt was not followed by natural molting later in the year.

It can be concluded that iodinated casein at low dosages causes a slight

but not entirely consistent acceleration in the gains in weight of young chicks. All investigators are in agreement that the rate of feather growth is increased. Further investigations on the relation between the response to iodinated protein administration and such factors as the breed and strain of chicken, variations in the diet and variations in climatic factors should yield results of considerable interest.

While the Missouri workers and Astwood and his associates have shown that in the young chick, beginning a few days following birth, feeding goitrogens increases thyroid weight and induces hypothyroidism, it is not at this stage of growth that the use of thiouracil would appear most useful (Astwood, Bissell and Hughes, 1944; Mixner, Reineke and Turner, 1944). Kempster and Turner (1945) have shown that even when chicks 10 weeks old are fed 0.2 percent thiouracil growth is depressed or in shorter trials unaffected, while Andrews and Schnetzler (1946) have observed growth depression even with 0.025 percent of thiouracil in the diet. In Kempster and Turner's trials there was a decrease in efficiency of food utilization while, in Andrews and Schnetzler's where additional light increased the food intake, a statistically significant increase in efficiency occurred. In both cases a marked increase in fat deposition and in market grade was observed. These results have been substantially confirmed (Mixner, Tower and Upp, 1946) using still larger and heavier birds (16 weeks of age), and maintaining food consumption by free range management. Glazener and Jull (1946a), however, feeding rations containing 0.1 and 0.2 percent thiouracil, throughout the first ten weeks of life found growth depression. These workers found the carcasses of such birds of poor quality, though all previous workers had commented favorably on this aspect. Andrews and Schnetzler, in fact, showed that the fat content of the skin increased by 26–44 percent largely depending on sex, while the increase in fat deposition in thyroidectomized chickens is well established (Greenwood and Chu, 1939). The decrease in rate of gains observed in chicks receiving 0.2 percent thiouracil in the ration has been prevented (Morenz and Shaffner) by the inclusion of 1 or 3 gm. iodinated protein per 100 lbs. of feed.

Similar increases in fat deposition have been secured in turkeys. Increases of 42 percent and 21 percent in the deposition of abdominal fat of males and females, together with improvement in carcass grade have been reported (Reineke, Davidson, Wolterink and Barrett, 1946). Henderson, Carver and Stephenson (1948) reported superior gains, food efficiency and fattening in turkeys receiving a 30 mg. stilbestrol implant and fed a ration containing 0.2 percent thiouracil. In younger turkeys (Blakely and Anderson, 1948) thiouracil increased fat deposition, but reduced the economy of gains. The results of Pipes and Turner (1946, 1948) suggest that the thiouracil content

of the tissues would not be sufficient to make the carcasses unfit for human consumption.

It is obvious from these results that the maximum effect on carcass quality and the minimum depression of gain in weight occurs when thiouracil is given after the early stages of growth are complete. Its use in the rations of rapidly growing young chicks is not feasible for growth is retarded. True growth is probably retarded at any age by induced hypothyroidism, but in terms of gain in weight and fat deposition it is not so apparent in the older animal. It can be concluded, therefore, that mild hyperthyroidism for a very short period followed by thiouracil treatment for a period immediately prior to slaughter is a method which will modify the growth and fattening of poultry for table production. The economic possibilities have not yet been explored and no comment can be given as to its future value compared with other methods of alteration of body conformation.

Increasing Egg Production by Feeding Iodinated Proteins

Thyroidectomy of the hen reduces her egg production (Winchester, 1939, 1940; Taylor and Burmester, 1940). This ranges from a slight reduction when thyroidectomy is incomplete to 70–80 percent when a completely hypothyroid individual is obtained, but attempts to restore egg production to the preoperative level by thyroxine administration have not been altogether successful. Thiouracil feeding retards the moult of hens (Glazener and Jull, 1946b) but was not observed to have a significant effect on egg production. On the other hand Berg and Bearse (1948) recorded a decline in egg production of pullets receiving thiouracil.

In 1925 Crew reported a remarkable "rejuvenesence" of seven hens, 5–8 years of age, following the feeding of desiccated thyroid gland. The birds molted rapidly at the beginning of treatment and their new plumage was of a more juvenile type. The low egg production of 6.7 eggs in six months increased to 34 eggs in the same period of time. No comparable effect on egg production was noted by Cole and Hutt (1927), but Zawadowsky, Liptschina and Radsiwon (1928) noted an increase from only 10–50 mg. of desiccated thyroid per day. Previously, Crew and Huxley (1923) had not observed any acceleration of egg production in trials in which small doses had been fed to younger hens. A depression of egg production was noted by Asmundson (1931), when large amounts were given.

These observations would suggest that iodinated protein feeding at optimal dosages might increase egg production especially in older hens. Turner's group at Missouri, in a continuous trial lasting for five laying years, has studied this possibility.

In the first experiment (Turner, Irwin and Reineke, 1945), conducted with White Leghorn hens in their second year of production, a group receiving 10 gm. iodinated protein per 100 lbs. of feed had a yearly egg production record of 40.6 percent compared to 22.6 percent for the control group. Five gm. iodinated protein per 100 lbs. feed was suboptimal while 20 gm. appeared to be excessive. In the 4 subsequent laying years hens receiving iodinated protein at the 10 gm. level continued to lay at a considerably higher rate than normal controls of the same age (Turner, Kempster, Hall and Reineke, 1945; Turner, Kempster and Hall, 1946; Turner and Kempster, 1947, 1948). In fact in the last year recorded, hens in their sixth laying year averaged 118.5 eggs per bird compared to 35.1 for their controls. Thus these experiments indicate that iodinated protein fed at a low level may be used to prevent in part the yearly decline in egg production due to the senescent changes associated with advancing age. The principal effect noted was maintenance of egg production during hot weather when a decline normally occurs that parallels the seasonal decline in metabolism (Brody, Funk and Kempster, 1938; Winchester, 1940). There was no demonstrable effect on mortality with the small numbers of hens involved, though the hyperthyroid birds weighed less than the controls. At post mortem examination, the ovaries were heavier and there was a characteristic hypertrophy of the adrenals.

Rhode Island Reds receiving 10 gm. iodinated protein in their pullet year showed a significant increase in egg production above their controls only during the summer (Turner, Kempster, Hall and Reineke, 1945). In White Plymouth Rocks, which have a relatively low thyroid secretion rate (Schultze and Turner, 1945), iodinated casein-fed birds showed an increase in egg production that was maintained during the year instead of being confined to the summer months (Turner, 1948).

Gutteridge and his associates, in short term trials designed for other purposes found no increase in egg production on feeding iodinated casein, though his experiments were made toward the end of the laying season (Gutteridge and Pratt, 1946; Gutteridge and Novikoff, 1947).

The effect on the weight of the egg has been studied and it appears that there is a decline in egg size during hyperthyroidism (Asmundson, 1931; Asmundson and Pinsky, 1935). Crew and Huxley, using small doses of desiccated thyroid did not observe such an effect, and Turner's group working with small doses of iodinated casein observed only a slight decline of doubtful significance. It appears that this effect on size is only apparent at the higher levels of stimulation for in Asmundson's experiments egg production was often stopped, especially in small birds in which the effect of a constant dose of thyroid was consequently greater. At these high

dosages, yolk size is diminished, an effect which is not due to physiological under-nutrition but to a reduction in the rate of growth of the ovum. The albumen is not affected, but shell weight is increased. This effect has been confirmed by Gutteridge and Novikoff (1947). It is of some interest and possibly of some practical importance that iodinated casein feeding counteracts the decline in shell weight and strength characteristic of the end of the laying season and also occasioned by reduced daylight and high temperature. Hoffmann and Wheeler (1948) reported that in Rhode Island Red pullets fed 10 gm. iodinated protein per 100 lbs. feed from June to October there was a highly significant improvement in egg shell quality accompanied by losses in body weight and egg production. A variable improvement in egg shell thickness together with losses in body weight was also noted by Berg and Bearse (1948). Conversely the feeding of 0.1 percent thiouracil decreased egg shell thickness. In pullets fed iodinated protein during the growing period the onset of egg production was retarded from the 20th to the 25th week (Wheeler and Hoffmann, 1948a). This is rather surprising since the testes weights of cockerels on the same treatment was increased. Wheeler and Hoffmann (1948b) have also reported that in pullets fed iodinated casein from the day of hatching the fecundity was increased significantly above that of control birds. The fertility was unchanged but the incubation period was prolonged, and the chicks had enlarged thyroids. This curious phenomenon has also been noted by McCartney and Shaffner (1948) and is believed by both groups of workers to indicate that the chicks from hyperthyroid hens are themselves hypothyroid. The thyroid size is reduced to normal, however, after 15 days on a standard diet (Wheeler and Hoffmann, 1948b).

In contradistinction to the results reviewed thus far, Hutt and Gowe (1948) reported that, except for a slight reduction in the number of eggs laid during the first three months on experiment, iodinated protein showed no effect on egg production. Neither did it show any measurable effect on body weight, egg weight, eggshell strength or viability.

Little work has been carried out on egg composition. Asimov, Estrin and Miletzkaya (1931) report an increase in egg iodine following thyroid feeding, but Turner, Irwin and Reineke (1945) have been unable to demonstrate a transfer of thyroxine to the egg on iodinated casein feeding. No change in albumin index was noted in eggs from hens fed 15 gm. iodinated protein per 100 lbs. feed (Berg and Bearce, 1948).

The data on the influence of mild hyperthyroidism on both egg production and composition are extremely suggestive. From the divergent results reported, however, it is evident that a great deal of research must yet be done before the role of the thyroid hormone can be clearly elucidated. It seems clear that this hormone is only one in a complex of factors that can

influence the process of egg production and it seems likely that these other factors might vary from one laboratory to another. If this is true little agreement can be expected until the effect of such variables, particularly as influenced by modifications in thyroid function, has been determined.

Summary and Integrating Discussion

The literature on the physiologic effects of thiouracil and thyroidal substances has been reviewed, with particular attention to possible applications of these compounds in the principal classes of livestock, namely, dairy cattle, beef cattle, sheep, swine, and poultry.

By virtue of its thyroid-inhibiting property thiouracil will cause a depression of milk and egg production and when given to very young animals will cause growth stasis and varying degrees of cretinism. When given only during the last three to four weeks of the fattening period in chickens and turkeys, however, and the last four to six weeks in swine, this drug has caused significant improvement in the economy of gains in most cases with little depression in the rate of gain. Increased fat deposition has usually been observed in poultry, but not in swine. Results with thiouracil in beef cattle and sheep have been inconsistent, presumably because the optimal conditions for administration of the drug have not been established.

The use of thyroidal substances for the stimulation of milk production has been investigated quite extensively. Within a limited range the percentage increase in milk yield is roughly proportional to dosage. Fat percentage also increases, the increase usually appearing at lower dosage levels than the rise in milk yield. With the exception of a small and variable decrease in milk nitrogen no other important alterations in milk composition have been reported. Thyroid hormone is not transmitted to the milk. It is concluded that milk from cows fed iodinated protein is safe and nutritionally adequate.

It is well established that thyroidal stimulation of dairy cows must be accompanied by an increase in nutrient intake if losses in body weight are to be avoided. If sufficient extra nutrients are supplied to support both the increased metabolism and the increase in production, normal body weights are maintained. It is extremely important to keep the dosage within the "physiological tolerance range" of the cow, particularly in long time feeding programs, in order to avoid overdosage. On the basis of present information it appears that thyroidally active iodinated protein could be used profitably during periods of milk scarcity to stimulate production for periods of about two months. Under good conditions of feeding and management and proper regulation of dosage it could be used in commercial herds for more extended periods. Until more information is available on the long term effects, the use of iodinated protein in purebred breeding herds would appear questionable.

Iodinated protein is poorly tolerated during hot weather. However, further research at low levels of dosage would be of interest.

Iodinated protein has proved beneficial in improving libido and fertility in sluggish and inactive bulls, and may provide a means of extending the period of usefulness of some herd sires. It has also been found to overcome "summer sterility" in rams although no practical experiments on the use of this method for lengthening the breeding season of sheep have been reported.

Conclusive information on the effects of iodinated protein on lactation in sows has not thus far been reported. When fed to young growing pigs, within a critical dosage range, iodinated protein has caused some increase in the growth rate together with a slight improvement in economy of gains. The pigs appear thicker bodied, more mature and more uniform in conformation than control animals. Results on carcasses range from no effect to some increase in weight of loin and bacon cuts.

In chicks iodinated protein consistently causes a pronounced acceleration of feather growth. Effects on body growth are variable, depending upon the dosage level given, the breed and strain of chicks and probably other factors.

Small amounts of iodinated protein given continuously in the ration have been reported to prevent partially the summer decline in egg production and also to retard the yearly rate of decrease in egg production with advancing age. Since agreement among several laboratories is poor, however, more research will be required to assess the possible role of thyroidal stimulation in egg production. Iodinated protein has also been reported to improve egg shell quality, but again there is some variability between laboratories, indicating the need for further research.

Because of the newness of this line of investigation any conclusions that can be drawn at this time as to the potential usefulness of alterations of thyroid function in the various fields of animal production are definitely limited in their scope. As in all new fields of investigation the solution of one problem invariably calls attention to several others that are awaiting solution. The introduction of goitrogens and thyroactive iodinated proteins, which permit control of the thyroid function at will, not only gives promise of some applications of economic importance, but also provides a research tool that should help to advance a step farther the frontiers of our knowledge of the physiologic processes upon which livestock production is based.

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THE RELATION OF FACE COVERING TO LAMB AND WOOL PRODUCTION IN RANGE RAMBOUILLET EWES

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WOOL covering has been developed on the face of some breeds of sheep because early breeders thought that covered faces were associated with heavy fleece weight. However, Marshall (1920) found that open-faced Rambouillet ewes had heavier fleece and body weights than wool-blind ewes. These results were confirmed by Spencer *et al.* (1928) who showed that Rambouillet ewes with the barest faces had heavier fleece weights, both unscoured and scoured, than those having heavily covered faces.

More recently Terrill (1941) found that Rambouillet ewes with open faces produced nearly 9 pounds more lamb per year than those with covered faces. These results were based on the lifetime lamb production of 393 registered ewes born at the U. S. Sheep Experiment Station from 1925 to 1934. The advantage of the open-faced ewes was mainly due to a higher percent of lambs born and weaned although there was also an advantage of nearly a pound in weaning weight. In this study little or no relationship of face covering to wool production was found. There was a slight tendency for ewes with open faces to have lighter grease fleece weights. Peters (1945) also found that open-faced Rambouillet ewes weaned more pounds of lamb per ewe per year than those with covered faces. Results from Texas (1945) showed that a much higher percent of open-faced Rambouillet ewes dropped lambs than of covered-face ewes.

Because of the economic importance of face covering, as indicated by its relationship to lamb production, further analyses were made at the Western Sheep Breeding Laboratory using more recent data. The purpose of this study was to determine further the relationship of face covering to lamb and wool production and to study the specific phases of reproduction responsible for the differences in lamb production.

Data and Methods

Data on face covering, lamb and wool production were taken from 798 Rambouillet ewes born during the years from 1938 to 1940 at the Western Sheep Bleeding Laboratory, Dubois, Idaho. These were the most recent

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groups in which lifetime lamb and wool production data were available. In addition, data on yearling wool production were obtained on 1701 Rambouillet ewes born during the years from 1941 to 1946.

The ewes were scored for face covering just before shearing at yearling age by each of three experienced animal husbandmen. Wool covering on the face was scored as follows: "1" not covered beyond the poll, "2"covered to the eyes, "3" covered slightly below the eyes but open faced, "4"covered below the eyes but not entirely covered and subject to wool blindness, "5" almost or entirely covered and subject to wool blindness. Face covering in Rambouillets is usually restricted to the last three scores. Illustrations of faces of Rambouillet yearling ewes showing various degrees of face covering are presented in figure 1. Nine scoring units were possible by assigning plus or minus values to ewes considered as being slightly above or below an even unit. Average scores of the committee were used in the analysis. Rambouillet ewes with a score of 3+, 3 or 3− are generally referred to as open-faced; those with a score of 4+, 4, or 4− as partially covered; and those with a score of 5+, 5 or 5− as covered.

Grease fleece weight, clean fleece weight and staple length were recorded for all yearling ewes. Grease fleece weights were taken on the shearing floor during the latter part of May or the first part of June and were recorded to the nearest 0.1 pound. Clean fleece weights were estimated from the clean yields of small side samples (about 35 grams) and grease fleece weights on yearlings born from 1938 through 1941. Staple length was measured at the side to the nearest 0.2 centimeter just before shearing.

Data on lamb and wool production were tabulated for each ewe year for the first 5 lambing years, although all ewes having at least 1 lambing year were included in the study. Lambing data for ewe years in which the ewe died before weaning time were excluded.

Information as to whether the ewe lambed, number of live and/or dead lambs born, number of lambs weaned, weight of lambs weaned and grease fleece weight was recorded each year. Lambs given to a foster mother were credited to their own mother as being born alive but to their foster mother for weaning data.

The ewes were maintained under typical range conditions for the Intermountain West. The ewes were herded on sagebrush-grass range near Dubois, Idaho from the latter part of September until breeding in November or December. They were fed hay and bred in pens for about 30 to 34 days. After an interval of a few days a few rams were turned in for range breeding for an additional 15 to 30 days. The ewes were herded on the fall or winter range until sometime in January when they were taken to the feed lot and fed alfalfa hay until the spring range was ready in the latter part of April.

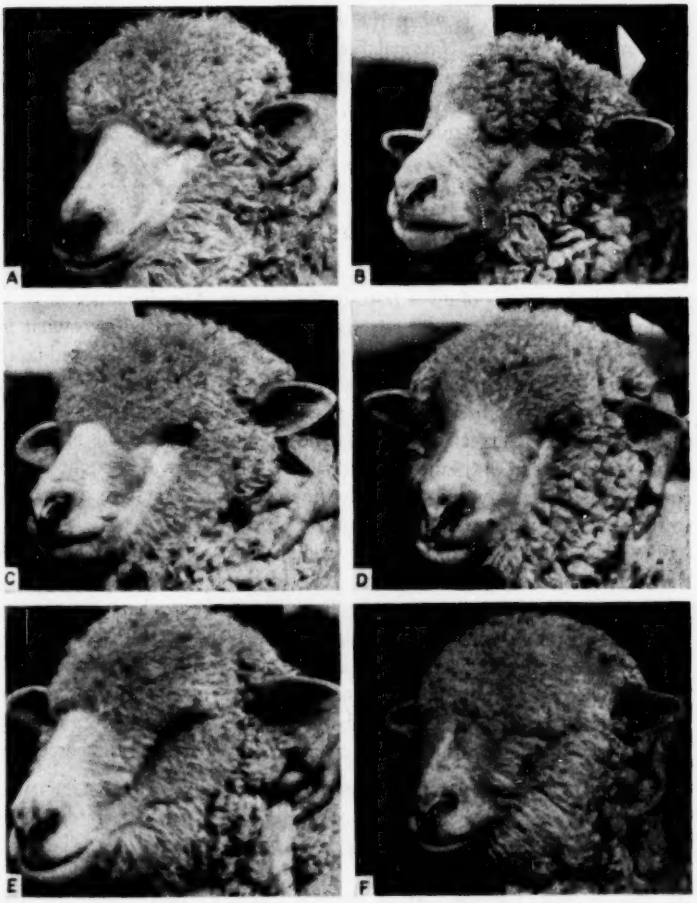

Figure 1. Face covering of yearling Rambouillet ewes. A, open face with score of 3; B, C and D, partially-covered faces with scores of 4+, 4 and 4− respectively; E and F, covered faces with scores of 5+ and 5 respectively.

A protein supplement or oats was fed from about a month before lambing until the ewes were turned on the spring range. The lambs were born in April and May and were herded with their dams on the sagebrush-grass range until about July 1, when the flock was trailed to the high summer range near the Targhee National Forest. They remained on the summer range until weaning time in the latter part of August. The average age at weaning was around 130 days.

All ewes included in this study which were subject to wool blindness had the wool clipped from around the eyes about three times a year. Thus, the differences in production occurred in spite of this corrective treatment.

Results and Discussion

The relation of open-face to greater lamb production was fairly consistent for each of the groups of ewes born in the 3 years. The difference in lamb production between open and covered faced ewes decreased somewhat in the successive years. Also more ewes were classified in the covered-faced group and less in the open and partially covered groups in the succeeding years. This may have been the result of changes in scoring standard, which often occurs with subjective methods and may have caused the narrowed differences between open and covered-faced groups. It was thought that a combination of the 3 years would give the most representative differences so the 3 groups were combined for further study.

The relation of face covering to various phases of lamb production is shown in table 1. Open-faced ewes excelled those with covered faces in every phase of lamb production including percent of ewes lambing, percent of lambs born of ewes lambing, live lambs as percent of lambs born, lambs weaned as percent of live lambs born and average weaning weight, although the difference was slight for live lambs as percent of lambs born, and for lambs weaned as percent of live lambs born. Each of these factors is fairly independent although as the percent of lambs born increases, the percent of

TABLE 1. RELATION OF FACE COVERING TO LAMB PRODUCTION

Face covering	No. of ewe years	Percent ewes lambing of ewes bred	Percent lambs born of ewes lambing	Percent live lambs of lambs born	Percent lambs weaned of live lambs born	Average weaning weight in pounds	Percent lambs weaned per ewe bred	Pounds lamb weaned per ewe bred
Open	286	95.5	126.7	91.9	89.0	76.3	99.0	75.5
Partially covered	845	95.4	124.2	92.3	88.1	74.8	96.3	72.1
Covered	1557	91.9	119.7	90.0	88.6	73.4	87.7	64.4

lambs weaned and the weaning weights are apt to decrease since mortality is higher and weaning weights are lighter for twins. The last two columns in table 1 represent the combined effect of the preceding factors, showing that ewes with open faces wean 11.3 percent more lambs and 11.1 more pounds of lamb per ewe bred than ewes with covered faces.

Production of ewes with partially covered faces was much closer to open-faced ewes than to covered-faced ewes for all features of lamb production except percent of live lambs weaned and weaning weight. They weaned 8.6 percent more lambs and 7.7 more pounds of lamb per ewe bred than ewes with covered faces. This indicates that some progress toward more open faces is immediately reflected in increased lamb production under range conditions.

Differences in lamb production within the groups presented in table 1 were found for the various degrees of face covering, particularly for the partially covered and covered-faced groups. For instance, ewes given a score of 5 weaned 62.8 pounds of lamb while those with slightly more open faces, having a score of 5+, weaned 66.4 pounds of lamb per ewe bred. Of those with partially covered faces, ewes given a score of 4− weaned 70.7 pounds of lamb, those scored 4 weaned 72.4 pounds of lamb, and the most open-faced of the partially covered ewes with scores of 4+ produced 74.9 pounds of lamb per ewe bred. The average age at weaning was around 130 days. This consistent increase in lamb production as the scores progress toward more open faces leads to confidence in the value of even small improvements in removing the face covering from range sheep.

The advantage of open-faced ewes over those with covered faces in lamb production was apportioned to specific phases of reproduction. The end point of reproduction in this case was taken as weaning weight since this is the nearest approach to market weight that can be made from these data. These estimates were obtained by determining the effect of the differences in each phase of reproduction of the pounds of lamb weaned per ewe bred. The difference between ewes with open and covered faces in percent of ewes lambing caused a difference of 2.07 pounds of lamb weaned per ewe bred. A greater number of lambs born from the open faced ewes resulted in a difference of 5.17 pounds of lamb per ewe bred. More lambs born alive from the open faced ewes produced a difference of 0.96 pound of lamb weaned, and heavier weaning weights of lambs from open-faced ewes produced a difference of 2.96 pounds of lamb per ewe bred. Thus, about 46 percent of the advantage of open-faced ewes was due to a greater number of lambs born per ewe lambing; 26 percent was due to higher weaning weights; 19 percent was attributed to a higher proportion of the open-faced ewes having lambs; and 9 percent was due to greater viability to weaning

of offspring from the open-faced ewes than from those with covered faces.

The effect of age of ewe on the relation of face covering to lamb production is shown in table 2. The greatest advantage for open-faced ewes in pounds of lamb weaned per ewe bred was found at 3 years of age followed in order by 2, 4, 6, and 5 years. The ewes were sorted into the face-covering groups on the basis of yearling scores. General observations indicate that ewes become somewhat more open-faced as they grow older and in addition

TABLE 2. EFFECT OF AGE OF EWE ON THE RELATION BETWEEN FACE COVERING AND POUNDS OF LAMB WEANED PER EWE BRED

Face covering	Pounds of lamb weaned, per ewe bred, by—				
	2-year-old ewes	3-year-old ewes	4-year-old ewes	5-year-old ewes	6-year-old ewes
Open	54.4	78.1	83.4	84.6	95.7
Partially covered	48.9	69.7	87.2	91.3	82.1
Covered	44.0	63.6	74.6	78.2	88.8
Open minus covered	10.4	14.5	8.8	6.4	6.9

their face covering in later years is apt to vary more in either direction from their yearling score. In this event it would be expected that the advantage of the ewes with open faces as yearlings would decrease as the ewes grow older and there was a tendency in this direction after the third year of age.

The relation of face covering to wool production was studied in 2499 yearling Rambouillet ewes born from 1938 through 1946. On the average covered-faced ewes excelled those with open faces by 0.09 pounds of grease wool and 0.05 pounds of clean wool. Neither of these differences was significant. Covered-faced ewes had greater staple length by 0.16 centimeters than open-faced ewes. This difference was highly significant statistically. The within year correlation coefficients of each of the 3 fleece traits with face covering were low and nonsignificant, indicating that no important relationships existed. In general covered-faced ewes (born 1938–40) produced slightly heavier grease fleece weights (about 0.2 pound) throughout their lifetimes than open-faced ewes.

Discussion

The results indicate that the effect of covered faces in reducing lamb production probably comes about because the wool-blind ewes cannot see to eat as well or as much of the time and therefore are more poorly fed than those with open faces. The wool-blind ewes probably tend to follow the

ewes with open faces and therefore have to depend more on trampled and second choice feed on the range. They also have difficulty in getting to water.

Wool blindness is probably more detrimental at certain times of the year, particularly when the wool on the face has been permitted to grow for some time. Ewes are normally wool-blinded, or clipped around the eyes, in the fall before breeding (October), in the spring before lambing at crutching time (early March), and of course at shearing time (about June 1). Wool blindness would be most prevalent just before these dates. The most critical time is probably just before breeding in the fall as the effect of the lowered level of nutrition at this time on the wool-blind ewes most likely causes the differences in percent of ewes becoming pregnant and in number of lambs born (dependent on number of ova shed).

The much greater effect of face covering on proportion of ewes lambing noted in the Texas Station Report, 1945, than in this study may be attributed to the ewes in Texas having been bred in pastures, where wool-blind ewes might even escape being bred. This was not likely at this Laboratory as the ewes were all bred in small lots. At Texas the ewes were scored for face covering each year which might show the effects of face covering with advancing age more accurately than in this study.

The slight reduction in the viability of lambs from birth to weaning from the covered-faced ewes indicates that there is probably little effect of wool blindness during the spring and early summer. This may be due to clipping the wool from the eyes with machine clippers at crutching and shearing, which is probably more effective than clipping with blade shears in the fall.

The disadvantage in weaning weight of lambs from covered-faced ewes may be partly due to increasing degree of wool blindness in the late summer resulting in earlier reduction of milk supply of the wool-blind ewes. This difference may also be partly due to developing wool blindness in the lambs as ewes with covered faces are more apt to have lambs with covered faces (Terrill, 1941; Terrill and Hazel, 1943, 1946). Lambs sometimes become wool blind just before weaning and probably suffer from being less able to obtain milk from their mothers and feed through grazing. The use of open-faced sires might remove at least part of the detrimental wool blindness of the lamb as these lambs would probably be more open-faced than their dams.

The detrimental effects of covered faces might be partially corrected by more frequent clipping around the eyes, especially in late summer or early fall, though this is not often practical under range conditions. Elimination of wool blindness through breeding and selection would be much more

effective and would be permanent. Work at this Laboratory (Terrill and Hazel, 1943, 1946) has shown that the heritability of face covering is high (0.56 for weanling face score) and therefore may be readily changed by selection provided some variability in face covering exists. Where the incidence of open faces is low, i.e., variability in face covering is low, initial progress in selecting toward open face may be slow. The results reported here show that even slight progress toward more open faces will be immediately reflected in increased lamb production. The high economic importance and heritability of face covering indicate that it should receive as much or more attention in selection than any other trait in sheep, if wool blindness is a problem.

The slight relationship between covered faces and increased wool production is not large enough to be important. It is reasonable that wool blindness may appear earlier and be more apparent in those having long staple. There is also a tendency for weanling selections to retain the open faced ewe in spite of a light fleece but to cull the covered-faced ewe with a light fleece. The advantage in grease fleece weight of the covered-faced mature ewes may be explained by the greater lamb production of the open-faced ewes, as Terrill and Stoehr (1942) have shown that grease fleece weight is reduced by increased lamb production. In fact practically all of the disadvantage of the open-faced mature ewes in wool production can be explained by the effect of their greater lamb production.

Summary

The lifetime lamb production of 798 Rambouillet ewes born during the years of 1938 through 1940 at the Western Sheep Breeding Laboratory, Dubois, Idaho, was studied in relation to face covering.

Ewes with open faces produced 11.3 percent more lambs and 11.1 more pounds of lamb per ewe bred than those with covered faces. Ewes with partially covered faces weaned 8.6 percent more lambs and 7.7 more pounds of lamb per ewe bred than those with covered faces. Differences in face covering within these groups were associated with corresponding differences in lamb production. These advantages for ewes with open faces occurred in spite of three periodic clippings around the eyes of all ewes subject to wool blindness.

About 46 percent of the advantage of open-faced ewes was due to a greater number of lambs born per ewe lambing; 26 percent was due to higher weaning weights; 19 percent was attributed to a higher proportion of the ewes becoming pregnant; and 9 percent was due to greater viability to weaning of offspring.

Open-faced ewes excelled covered-faced ewes in lamb production at each

year of age. The greatest advantage for open-faced ewes in pounds of lamb per ewe bred was found at 3 years of age followed in order by 2, 4, 6, and 5 years.

The yearling grease and clean fleece weights and staple lengths of 2499 Rambouillet ewes and the lifetime grease fleece weights of 798 Rambouillet ewes were slightly greater for covered-faced ewes than for those with open faces. The differences were not significant except for staple length and were not large enough to be economically important.

The great economic importance and high heritability of face covering indicate that it should receive as much or more attention in selection than any other trait in sheep if wool blindness is a problem.

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BIRTH WEIGHTS AND AVERAGE DAILY GAIN IN HOTHOUSE LAMB PRODUCTION[1]

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HOTHOUSE lambs have been in popular demand by the large restaurants and hotels in the metropolitan area since about 1903. They afford a very good out-of-season drawing card on the menus and consequently are a very high priced product. The demand is limited, however, and therefore, the production is also limited.

The term "hothouse lamb" does not refer to a lamb reared in a greenhouse but rather, to one that is born out of season, and sold while still nursing. They are most profitably sold when they reach the weight of 32 to 36 pounds (Lewis and Christian, 1947). Hothouse lambs are also referred to as "winter lambs" or "incubator lambs."

The lambs are marketed with the head, feet, and pelt on, and the heart and liver are left in the carcass. The carcasses are graded in the New York market as extra fancy, fancy, good, fair, and poor. These grades are determined mainly on quality, conformation of the carcass and the abundance of kidney fat.

The purpose of this study was to determine the importance of breeding upon birth weight and average daily gain and to determine a correlation between the two, if any. The average birth weights were determined from 882 lambs of three pure breeds and seven cross-breeds. The average daily gains were computed from 787 lambs of the same breeding. The study includes all lambs born of the above breeding in the years 1930–1940.

Review of Literature

Savage and Tailby (1912) reported that the best and most economical prices were received from lambs that gained at least one-half a pound a day. Bonsma (1946) found cross-breeds of sheep produced a better quality progeny, earlier maturing and better mutton lambs than did pure breds. He also found that a three breed cross was better than a two breed cross.

Cole (1946) reported that the average width of a lamb had the highest relationship to the rate of gain of all the factors studied.

Henning and co-workers (1933, 1938, 1939, 1942, 1943) reported that ewes should be in good gaining condition when bred to produce large, healthy, and early lambs. They also found that lambs must be fed from a

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creep when they have reached about 10 days of age in order to put on enough weight and finish to sell for top prices.

Methods

This project has been carried on since 1924 and during these years the management of the flock has remained as nearly uniform as possible. The only variation in the project has been the breeding of the lambs.

The original ewes for this project, large, smooth-bodied "C" type, high grade Merino, were obtained in southwestern Pennsylvania and surrounding counties in Ohio and West Virginia. The Merino was used because of its "out-of-season" breeding habit and its availability. They were bred to registered Dorset and Corriedale rams and these crosses were bred to pure bred Southdown, Hampshire and Dorset rams throughout the ten years of the experiment.

TABLE 1. AVERAGE BIRTH WEIGHTS OF THE VARIOUS BREEDS AND CROSSES FOR EACH YEAR

Breed	Years									
	30–31	31–32	32–33	33–34	34–35	35–36	36–37	37–38	38–39	39–40
Merino					8.53		7.53	7.82		
Hampshire							8.76	9.56		
Hampshire×(Dorset-Merino)		7.78	8.22	8.44	8.81	8.50	9.62	8.70	9.41	9.2
Hampshire×(Corriedale-Merino)		7.93	9.70	9.45	7.61	8.50				
Southdown								7.46		
Scuthdown×(Dorset-Merino)	8.11	7.77	8.35	8.68	8.16	7.47				
Southdown×(Corriedale-Merino)		6.50	9.03	7.54	9.20	7.83				
Dorset×Merino					7.67		8.12	8.86	9.37	9.25
Dorset×(Corriedale-Merino)							10.11	10.13	10.9	9.74
Corriedale×Merino	7.81	7.32								

The ewes were bred between the first of April and the middle of July. The ewes remained on pasture until about the first of September, when they were brought to the barn and were fed about one-half pound of grain per day plus good hay. Normal trimming and care of the ewe was carried out until the ewe lambed. Upon lambing the ewe and lambs were separated and placed in an enclosure 4 feet square or a lambing hurdle. Immediately upon birth the lambs were weighed and a record of weight, sex, date and breed was made. The lambs were creep fed after reaching ten days of age and were fed a mixture of 40 pounds of cracked corn, 10 pounds of clean oats, and 5 pounds of linseed oil cake (pea size). The lambs were weighed each day for the first thirty days and weekly thereafter. The lambs were slaughtered upon reaching the desired weight and upon demand of the market.

Results and Discussion

The results of the study for each year are summarized in tables 1 and 2 for the average birth weight and average daily gain for each kind of breeding respectively. Tables 1 and 2 show that there was a difference between years as well as a difference between breeding. This was true for both birth

TABLE 2. AVERAGE DAILY GAINS OF THE LAMBS OF THE VARIOUS KINDS OF BREEDING FOR EACH YEAR

Breed	Years									
	30–31	31–32	32–33	33–34	34–35	35–36	36–37	37–38	38–39	39–40
Merino					.37		.38	.36		
Hampshire							.53	.58		
Hampshire ×(Dorset-Merino)		.55	.52	.49	.58	.54	.64	.59	.61	.65
Hampshire ×(Corriedale-Merino)		.54	.57	.54	.52					
Southdown								.38		
Southdown ×(Dorset-Merino)	.54	.51	.46	.53	.52	.54				
Southdown ×(Corriedale-Merino)		.45	.34	.50	.56	.50				
Dorset×Merino					.49		.48	.51	.52	.57
Dorset ×(Corriedale-Merino)							.62	.61	.56	.60
Corriedale×Merino	.41	.43								

weight and average daily gains. Figures 1 and 2 show a breakdown of the lambs with respect to birth weights and average daily gain. Figure 1 shows that the males were .6 of a pound heavier at birth than the females and that the singles were 1.4 pounds heavier at birth than the twins. The average birth weight of all lambs was 8.5 pounds.

Figure 2 shows that the males gained .03 of a pound more than did the females which is not a significant difference; however, the singles gained .15 of a pound more per day than did the twins. The average daily gain of all lambs slaughtered was .53 of a pound per day.

In considering all the lambs with reference to breed it was found that the [Dorset × (Corriedale-Merino)] cross was significantly higher in both birth weight and average daily gain as shown in figures 3 and 4. These figures show that the three breed crosses sired by the Hampshire and Dorset rams are higher than the Southdown sired crosses. They also showed that the three breed crosses are generally better than the two breed crosses.

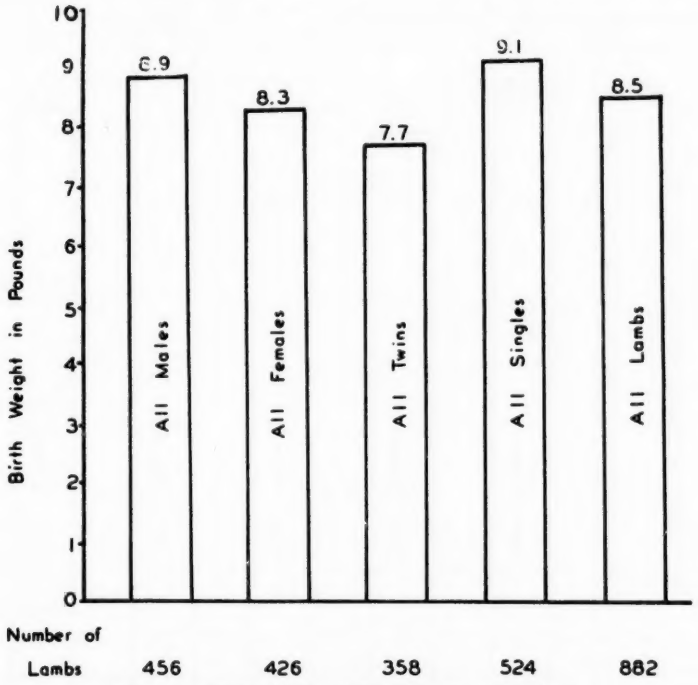

Figure 1. Average birth weights of all males, females, twins, singles, and all lambs.

It is also shown in figures 3 and 4 that the pure bred Hampshires compare very favorably with the cross breeds but they lack the out-of-season breeding trait which is very essential in hothouse lamb production.

After the three-breed cross of [Dorset × (Corriedale-Merino)], the other breeds were in the following order in most cases. The purebred Hampshire and [Hampshire × (Dorset-Merino)] were always close. The [Southdown × (Dorset-Merino)] and [Hampshire × (Corriedale-Merino)] were always close. The (Dorset Corriedale) compared favorably with the [Hampshire

×(Corriedale-Merino)] although the (Dorset×Corriedale) was similar to the purebred Merino and Southdowns in almost all cases.

The Southdown crosses were smaller at birth and usually slower to gain but when slaughtered they had the highest percentage of the top three grades as shown in table 3. The [Southdown×(Corriedale-Merino)] lambs all graded in the top three grades covering 61 lambs over the 10-year period.

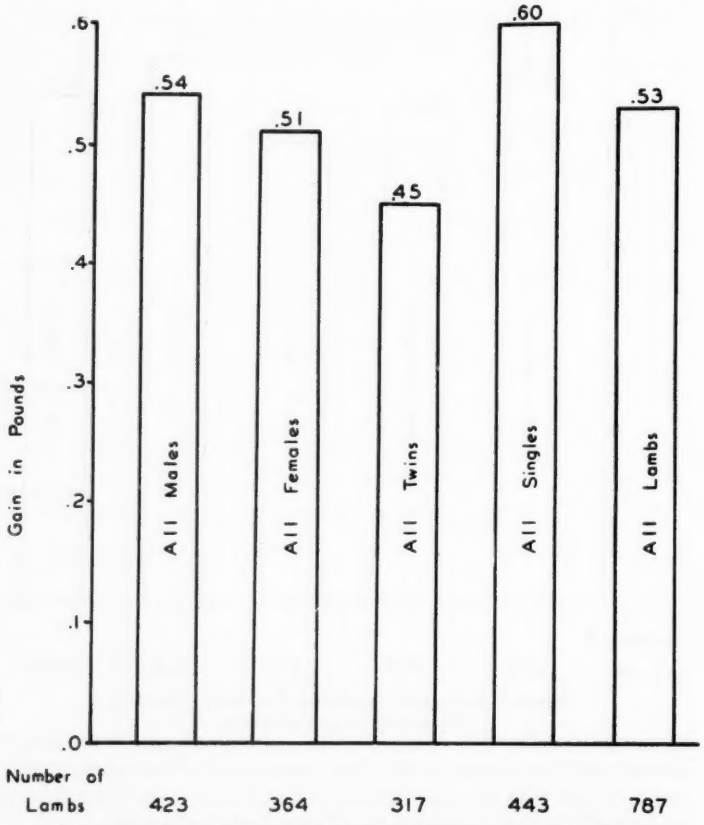

Figure 2. Average daily gain of all males, females, twins and singles.

In carcass grades alone it was found that the Corriedale-Merino mated to any mutton ram produced very good carcasses and, again, the [Dorset ×(Corriedale-Merino)] was somewhat better than the other crosses in that 48 percent of all these carcasses graded fancy. Lewis (1947) found that over a period of years there was about $4 difference between the top three

grades and the lowest three. This emphasizes the fact that we must have a fast growing, high quality lamb to bring the top price. Until just recently, lambs were sold by carcass and no allowance was made for weight. Ninety percent of the 380 lamb carcasses studied were placed in the top three grades. The (Dorset×Merino) had the lowest percentage of high grade carcasses.

Table 4 shows a breakdown of percentages of males, females, twins, and singles according to breeding. Fifty-two percent of the 882 lambs studied

TABLE 3. CARCASS GRADES, NUMBER, AND PERCENT OF LAMBS SLAUGHTERED FOR EACH KIND OF BREEDING

Breed	—Carcass grades—											
	Fancy		Choice		Good		Medium		Fair		Poor	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Hampshire ×(Dorset-Merino)	8	7	37	34	53	48	4	4	6	5	2	2
Southdown ×(Dorset-Merino)	5	6	44	49	31	34	3	3	7	8		
Hampshire ×(Corriedale-Merino)	6	11	30	54	19	34	1	2				
Southdown ×(Corriedale-Merino)	15	25	30	49	61	26						
Dorset×Merino	9	24	7	18	9	24	9	24	4	10		
Dorset ×(Corriedale-Merino)	12	48	6	24	5	20	2	8				
Total lambs	55		134		133		19		17		2	
Percent of carcasses in each grade	14		41		35		5		4		1	

for the 10 years were males and 41 percent were twins. It was found that the (Corriedale×Merino) cross had the greatest percentage of males with 47 out of 56 lambs being males; most of the other breeds were close to the expected 50 percent ratio. It was found, also, that 41 percent of all the births were twins with the [Southdown×(Corriedale-Merino)] crosses having the greatest percentage. The trait of twinning can not be fixed to any one breed from this study but the study tends to show that this is an individual trait rather than a breed characteristic.

In an effort to determine a correlation between birth weight and average

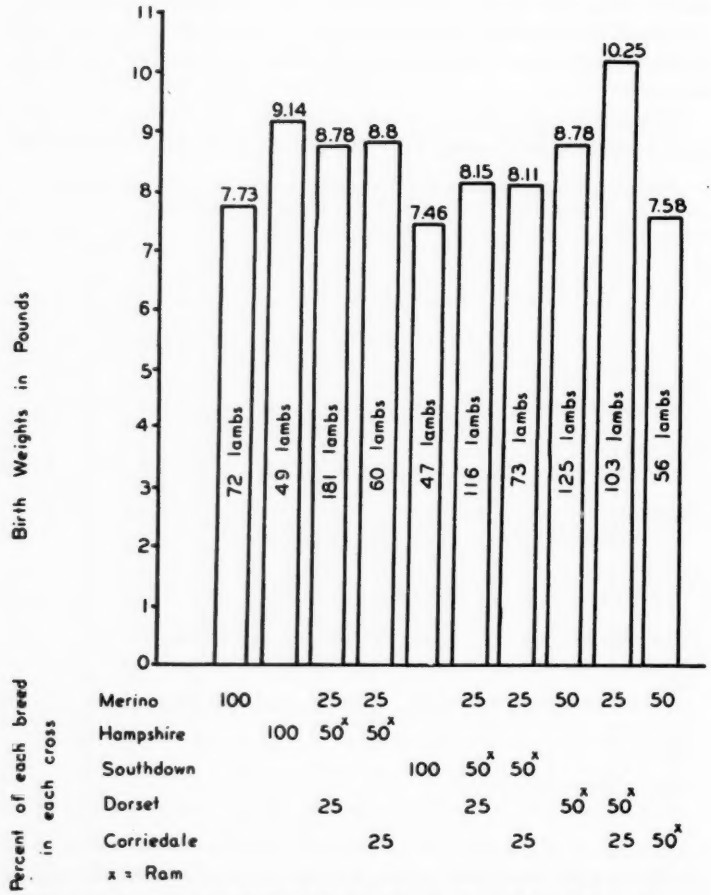

Figure 3. Average total birth weight of all lambs of each kind of breeding.

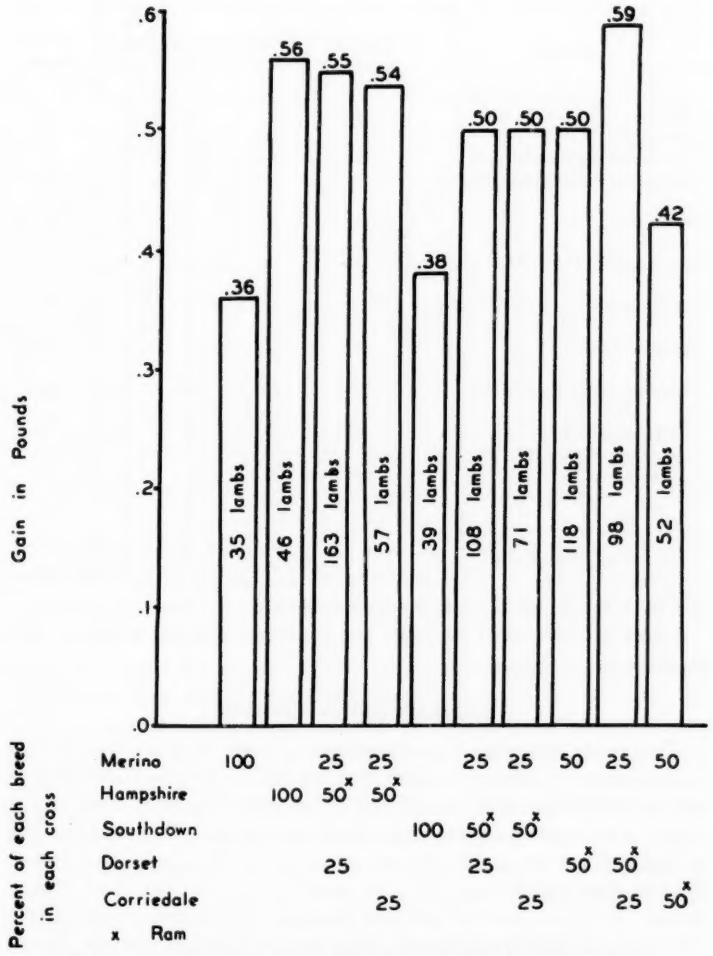

Figure 4. Average daily gain of all lambs of each kind of breeding.

TABLE 4. THE PERCENTAGE OF MALES, FEMALES, TWINS AND SINGLES OF THE DIFFERENT KINDS OF BREEDING

Breeding	Total No. animals	Percent males	Percent females	Percent twins	Percent singles
Merino	72	60	40	61	39
Hampshire	49	55	45	63	37
Hampshire×(Dorset-Merino)	181	51	49	49	51
Hampshire×(Corriedale-Merino)	60	50	50	23	77
Southdown	47	47	53	64	36
Southdown×(Dorset-Merino)	116	50	50	75	25
Southdown×(Corriedale-Merino)	73	49	51	19	81
Dorset×Merino	125	49	51	12	88
Dorset×(Corriedale-Merino)	103	50	50	10	90
Corriedale×Merino	56	82	18	43	57
Totals	882	52	48	41	59

daily gain, three groups of 20 lambs each were used. These groups were comprised of lambs slaughtered at different ages and the average daily gains and birth weights of the lambs were determined.

Figure 5 shows that the larger the lamb at birth, the sooner it will reach slaughter weight.

Summary and Conclusions

This study was largely a comparison of birth weights and average daily gains on 10 different kinds of breeding used in hothouse lamb production and indicates that the [Dorset×(Corriedale-Merino)] cross is the largest at birth and gains the fastest of all lambs studied. This cross also had a very high percentage of high quality carcasses. The study also showed that the three breed crosses are more desirable than the two breed crosses. It was found, also, that the purebred Hampshire lambs compare very favorably with the three breed crosses. However, as a general practice, Hampshires are not used extensively in hothouse lamb production because of the fact that they will not normally breed in May, June, and July in this area.

The three mutton type rams studied in the report rank in the order of Dorset, Hampshire, and Southdown. The results show that the Southdown ram does not sire as large a lamb as the Hampshire or Dorset rams, nor do the

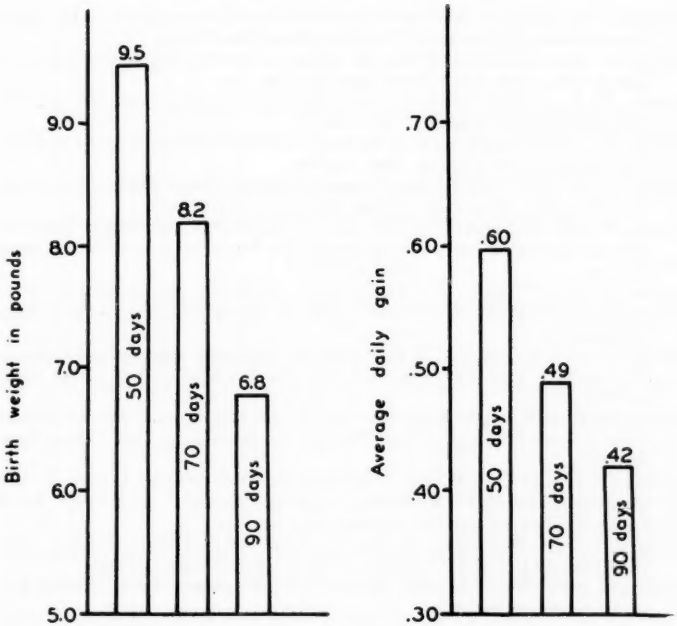

Figure 5. Birth weights and daily gains of groups of twenty lambs that were ready for slaughter at different ages—50 days, 70 days and 90 days.

lambs gain as fast, but the pedigreed Southdown ram does sire lambs of more finish and quality that sell for a higher price.

Tht study shows that in the 882 lambs of 10 breeds and crosses used, the average birth weight was 8.5 pounds. The average birth weight of 456 males was 8.9 pounds; 426 females, 8.3 pounds; 358 twins, 7.7 pounds; and 524 singles, 9.1 pounds. From the same population of 882 lambs, the male to female ratio was 52–48 while the twins to singles ratio was 41–59.

The average daily gain of 787 lambs was 0.53 pound per day. The average daily gain of 423 males was 0.54 pound; 364 females, 0.51 pound; 317 twins, 0.45 pound; and 443 singles 0.60 pound.

There tends to be a correlation between birth weights and average daily gains in lambs of the breeds studied in this experiment.

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SIZE OF LAMBS AT WEANING AS A PERMANENT CHARACTERISTIC OF NAVAJO EWES[1]

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Introduction

LAMBS represent one of the two major sources of income from range sheep production. Hence the ability of ewes to wean heavy lambs is an important economic characteristic in the breeding of range sheep, and considerable emphasis needs to be placed upon it in deciding which ewes should be culled and which kept for further breeding. Weaning weight is correlated with mature body weight (Terrill, 1939).

The ability of a ewe to provide care and nourishment for her lamb varies from one year to another, depending upon the environmental circumstances which influence both the ewe and the lamb. These environmental circumstances may prevail during prenatal or postnatal stages, and may influence the ewe only, the lamb only, or both the ewe and the lamb. The effects which some environmental factors have upon weaning weight can be measured. Examples of such factors are the year in which the lamb is born and raised, sex and age of dam. Corrections or adjustments for these effects increase the accuracy of estimating the genetic ability of ewes which have weaned one or several lambs. This procedure also enables the breeder to estimate more accurately the effect of heredity on growth rate of lambs.

One objective of this study was to measure the effects of several environmental factors upon the weaning weights of lambs. This information was needed in order to adjust weaning weights before computing an estimate of repeatability. In addition, it will be useful in adjusting the weaning weights in an actual breeding program. The second and more important objective was to estimate the degree to which the weaning weights of lambs produced is a constant characteristic of Navajo ewes. This information is needed to select accurately for greater weaning weights and to plan a breeding program which has maximum effectiveness.

[1] The data for this study were collected under authority of the Bankhead-Jones Act, by the Bureau of Animal Industry, U. S. Department of Agriculture, in cooperation with the Office of Indian Affairs, U. S. Department of the Interior, at the Southwestern Range & Sheep Breeding Laboratory, Fort Wingate, New Mexico.

[2] U. S. Department of the Interior and collaborating with the U. S. Department of Agriculture.

The assistance of Dr. L. N. Hazel and Mr. C. R. Henderson, Iowa State College, is gratefully acknowledged.

Results

Description of Data

The weaning weights of 1,506 lambs representing the lifetime production of 414 ewes used in this study were taken as a routine part of the breeding program of the Southwestern Range and Sheep Breeding Laboratory, Fort Wingate, New Mexico. All of the ewes were of Navajo breeding. However, rams of the same breeding were not necessarily mated each year to the same ewe. Matings were made largely on the basis of fleece type of ewe and fleece type of the offspring from given matings. The breeds of sire included were Navajo, Corriedale, Romney and Columbia rams; crossbred rams were also used. These were produced by mating Corriedale, Romney, and Columbia rams with Navajo ewes.

The first weaning weights were taken on lambs born in 1938 from ewes born in 1936. Other Navajo ewes were added in later years, and all of their lambs from 1938 to 1947 were studied. A preliminary analysis revealed no difference in the weaning weights of lambs produced by ewes of different ages from 4 to 7 years or by those from 8 to 11 years. Thus only 4 age groups of ewes were studied, those being 2, 3, 4 to 7, and 8 to 11 years of age.

In the unadjusted data the average weaning weight at approximately 139 days was 59 pounds and the standard deviation was 9.8 pounds.

Analysis of Data

Six environmental factors that were thought to have an important effect upon the weaning weights of the lambs were studied. These were: Year in which the lambs were born, age of dam, breeding of sire, type of birth and rearing, sex, and age of lamb at weaning.

Hazel and Terrill (1945a) found differences in weaning weights between ram lambs and ewe lambs, single lambs and twin lambs, and lambs from mature ewes and those from 2-year-old ewes to be 8.3, 9.2, and 6.1 pounds respectively.

The method of analysis used in this study is the least squares method suggested by Yates (1934) and extended by Hazel (1946) and Henderson 1948). This method consists in fitting constants for each of the independent variables which in this case are the measurable environmental factors outlined above.

Table 1 shows the estimates of the deviations for each subclass of the major classification. All of the measurable sources of variation proved to be significant as shown by the analysis of variance in table 2, indicating that differences caused by each of the factors were not sampling accidents. The largest mean square was that for type of birth and rearing, indicating that the most important factor was whether a lamb happened to be born

TABLE 1. ESTIMATES OF DEVIATIONS FROM MEAN SHOWING THE VALUE FOR EACH SUBCLASS OF THE MAJOR CLASSIFICATION

Major classification	Subclass	Estimate of deviation
		(pounds)
Years	1938	0.00
	1939	−5.20
	1940	−4.30
	1941	6.90
	1942	1.60
	1943	0.80
	1944	−4.00
	1945	3.20
	1946	−5.20
	1947	6.50
Age Group of Ewes	2 years	−1.80
	3 years	1.50
	4– 7 years	1.70
	8–11 years	−1.40
Breeding of Sire	Navajo	−1.40
	Corriedale	1.10
	Romney	−2.30
	Crossbred	0.60
	Columbia	2.00
Type of Birth and Rearing	Single	4.70
	Twin	−6.50
	Twin raised as single	1.80
Sex	Rams	2.20
	Ewes	−2.20
Age of Lamb at Weaning, in days	Regression of weight on age	0.37

and reared as a single or as a twin. Differences caused by yearly variations were next most important. Variance due to regression on age at weaning was not analyzed separately from the other factors because of difficulties of computation, and because it appeared obvious that the increase in weight of 0.37 pound per day was a real source of variation.

The total sum of squares associated with the 1,505 degrees of freedom was 146,525, while the total reduction associated with the 20 degrees of freedom was 82,339. Thus 56 percent of the variance in weaning weight is due to the measurable environmental factors, in comparison with 49.5 percent reported by Hazel and Terrill (1945a) for Rambouillet lambs.

TABLE 2. ANALYSIS OF VARIANCE FOR ENVIRONMENTAL FACTORS

Source of variance	Degrees of freedom	Sum of squares	Mean squares
Total	1505	146,525	
Total reduction due to all measurable environmental factors	20	82,339	
Among years	9	17,329	1,925**
Among ages of ewes	3	2,645	822**
Among breeds of sires	4	2,728	682**
Among types of birth and rearing	2	37,057	18,528**
Between sexes	1	7,664	7,664**
Remainder	1485	64,186	43

** Indicates highly significant mean squares.

The mean square for the remainder in table 2 is 43, indicating that the standard deviation of weaning weights would be about 6.6 pounds in data adjusted for the environmental factors. These lambs by Navajo ewes are less variable in weight than are lambs of other breeds. The average weight of these lambs was 60 pounds as compared with 69.0 pounds for Rambouillets (Hazel and Terrill, 1945a), and 73.0 pounds for range Columbia, Corriedale, and Targhee lambs (Hazel and Terrill, 1946).

Adjustments of Weaning Weights for Environmental Effects

The estimates in table 1 were used to adjust the weaning weights for the lambs produced by each ewe, thereby correcting for the measurable environ-

TABLE 3. LIFETIME PRODUCTION OF ONE EWE ILLUSTRATING HOW ADJUSTMENTS FOR ENVIRONMENTAL FACTORS WERE MADE

Sire of lamb	Birth date of lamb	Sex of lamb	Weaning weight of lamb	Type of birth and rearing	Age of dam in years	Age of lamb in days
Navajo =+1.40	1939=+5.20	E=+2.20	68	S=−4.70	2=+1.80	153=−13
Navajo =+1.40	1940=+4.30	E=+2.20	64	T*=−1.80	3=−1.50	150=−10
Corriedale=−1.10	1941=−6.90	R=−2.20	72	S=−4.70	4=−1.70	136=− 4
Romney =+2.30	1942=−1.60	E=+2.20	53	T=+6.50	5=−1.70	142=− 2
Romney =+2.30	1942=−1.60	E=+2.20	56	T=+6.50	5=−1.70	142=− 2
Total +6.30	− .60	+6.60	+313	+1.80	−4.80	−23 (.37)

Adjusted total weaning weight of lambs for this ewe=313.79.

Most probable producing ability $= 60.1 + \frac{5(.22)}{1+4(.22)} \frac{313.79}{5} - 60.1 = 61.1$.

* Twin raised as a single.

mental factors. Separate observations were made on twin lambs and adjustments for them were made in the same way as for single lambs. Table 3 shows the lifetime lamb production of one ewe and illustrates how adjustments for environmental factors were made.

Repeatability of Weaning Weights

The final step in the analysis was to analyze the remainder shown in table 4 into a portion among ewes and an error term representing variance among lambs by the same ewe.

The figures needed for this final computation were the adjusted total weaning weights for each of the 414 ewes. Each adjusted total was squared and divided by the corresponding number of lambs. The total of these 414 values minus the appropriate correction factor gave the figure 27,957 for the sum of squares among ewes in table 4.

TABLE 4. ANALYSIS OF VARIANCE FOR ADJUSTED WEANING WEIGHTS

Source of variance	Degrees of freedom	Sum of squares	Mean squares	Composition of mean square	Estimates of components
Total	1505	146,525			
Reduction due to measurable environmental factors	20	82,339			
Remainder	1485	64,186			
Among ewes	413	27,957	67.74**	$\sigma_e^2+3.6320\sigma_a^2$	9.345
Error	1072	36,229	33.80	σ_e^2	33.800

** Indicates highly significant mean square.

$$\text{Repeatability}=\frac{\sigma_a^2}{\sigma_a^2+\sigma_e^2}=\frac{9.345}{9.345+33.800}=.217$$

The difference between the sum of squares for remainder and that among ewes gives 36,229 as the sum of squares for error. When tested against the mean square for error the mean square among ewes was highly significant.

The error mean square σ_e^2 represents the variance among lambs by the same ewe, with the effects of known environmental factors eliminated. The extra variance among lambs having different mothers σ_a^2 was found by applying the Winsor and Clarke (1940) formula for computing variance components in one-way classifications.

The ratio $\sigma_a^2/\sigma_a^2+\sigma_e^2$ is the intraclass correlation between the weaning

weight of lambs reared by the same ewe. This ratio was called repeatability by Lush and Molln (1942) in studying litter characteristics in swine. It is that fraction of the difference between two animals in one season which is most likely to be found between them in a later season. Another definition of repeatability is the fraction of the variance due to permanent differences between ewes. This fraction as applied to the weaning weight of lambs reared by Navajo ewes is .217 as shown in table 4.

Discussion

The figure .217 has its greatest usefulness in selecting ewes for the ability to wean heavy lambs. It is also useful in planning future breeding programs which will have maximum effectiveness in promoting genetic improvement.

Allowance must be made for the reduced variability of averages when comparing averages based on differing numbers of records. The correlation between repeated records (repeatibility) is needed for this.

The equation given by Lush (1947) for comparing without bias individuals which have unequal numbers of records is as follows: most probable producing ability of the ewe = the herd average $+ nr/1+(n-1)r$ times (ewes own average minus the herd average).

In applying this formula to the present case, n is the number of weaning weights in the ewe's average, r is the coefficient of repeatability, and the flock average for corrected weaning weights is 60.1 pounds.

Owing to the averaging of environmental errors, accuracy of selection increases with the number of records, and a larger fraction of the selection differential represents genetic improvement in increased weaning weights. However, this advantage is partly offset by the fact that the reduced variation among averages reduces the selection differential and prevents the breeder from reaching quite so far. Lush (1947) states that progress per generation when selecting among ewes with n records is $\sqrt{n/1+(n-1)r}$ times as large as the progress which could be made by selecting among ewes with only 1 record each. Thus, selecting on an average of 2, 3, 4, and 5 records is 1.28, 1.44, 1.55, and 1.63 respectively times as effective as if selection were made on only 1 record per ewe.

How much of this estimate of repeatability is due to the additive effects of genes and how much is due to epistasis, dominance, and permanent environmental factors need to be investigated for Navajo sheep. Hazel and Terrill (1945b) obtained estimates ranging from .27 to .34 for heritability of weaning weights of range Rambouillet lambs, this being considered as a characteristic of the lambs rather than of the ewes as is the figure of repeatability in this study. If this estimate is at all correct for Navajo lambs, then no more than about .08 of the .22 for repeatability can be attributed

to the additive effects of genes which express themselves directly in the growth rate of the lambs. The remainder, or .14, must be due to characteristics of the ewes which cause them to be consistently good or poor mothers quite independent of the kind of genes for growth rate which they transmit to their lambs.

Summary

The data analyzed in this investigation were weaning weights of 1,506 lambs, representing the lifetime production of 414 Navajo ewes. These data were collected from 1938 to 1947 as part of the routine records taken at the Southwestern Range and Sheep Breeding Laboratory, Fort Wingate, New Mexico. The unadjusted average weaning weight at approximately 139 days was 59.4 pounds with a standard deviation of 9.8 pounds.

Six measurable environmental factors were found to have important effects upon the weaning weights of the lambs: Year of birth, age of ewes, breeding of sire, type of birth and rearing, sex, and age of lamb at weaning. Weaning weights for 1939 and 1946 were 5.2 pounds below average and those in 1941 were 6.9 pounds above average. Two-year-old ewes weaned the smallest lambs; the 4 to 7-year-old group, the heaviest; and the 3-year-old and the 8 to 11-year-old group weaned intermediate weight lambs. Columbia rams sired the heaviest lambs at weaning, followed by Corriedale, crossbred, Navajo, and Romney rams. Single lambs were 11.2 pounds heavier than twins and 2.9 pounds heavier than twins raised as singles at weaning time. Ewe lambs averaged 4.4 pounds less at weaning time than ram lambs. The regression of weight on age at weaning was .37 pound per day. The variance attributed to each of the six factors was statistically significant, the total reduction amounting to 56 percent of the variance in the actual weaning weights.

Selection between lambs or between ewes can be made much more accurate by adjusting for differences in their environmental effects.

The repeatability coefficient for weaning weights of the lambs raised by Navajo ewes was .217. This estimate represents the degree to which the weaning weights of lambs is a constant characteristic of the ewes. Using averages of 2, 3, 4, and 5 records in practicing selection is respectively 1.28, 1.44, 1.55, or 1.63 times as effective as using only 1 record.

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THE EFFECT OF A LOW CAROTENE WINTER RATION ON THE BLOOD, MILK, AND LIVER CONCENTRATIONS OF VITAMINS A AND C OF EWES AND THEIR LAMBS[1]

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GOOD legume hay of some kind has long been considered an essential in the winter ration of breeding ewes in order to produce a thrifty, vigorous lamb crop. This roughage has been considered a good source of protein, minerals, and carotene for ewes.

In supplementing nonleguminous roughage, Harper (1940) was unable to secure satisfactory results by adding simple protein concentrates, simple mineral mixtures, or combinations of the two. Shrewsbury *et al.* (1942) supplemented a ration of oat straw, corn silage, and ground yellow corn with casein and cod liver oil. This improved the ration but the results were better when alfalfa hay was used. In later studies, Shrewsbury *et al.* (1943) obtained favorable results using dehydrated oat grass cake and alfalfa press juice. Both the dehydrated oat grass cake and alfalfa press juice had a relatively high content of ascorbic acid.

Since King *et al.* (1940) had shown that vitamins A and C were correlated in the bovine, and Phillips *et al.* (1941) had shown the importance of these vitamins in the newborn calf, this study was undertaken to observe the effect of an oat straw ration supplemented with protein and minerals as compared to an alfalfa ration, on the blood, milk, and liver concentrations of vitamins A and C in ewes and their lambs.

Experimental

During the 1945–46 season a straw ration was compared to a hay ration. Oat straw of good quality and free of weeds, legume seedlings, or other green material, was fed to the straw group. The hay group was fed good quality, bright colored alfalfa hay. One lot received the ration shown for the hay lot in table 1, and the other group received the ration shown for the straw lot. Eighteen aged, grade, Oxford-Shropshire ewes were allotted into these two lots on the basis of body weight and blood plasma vitamins A and C values.

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The ewes were maintained on these rations until turned out to native pasture June 20, 1946.

This experiment was repeated in 1946–47 beginning November 12, 1946, when the ewes were brought in from pasture. The remaining ewes for the previous season received the same rations as in the first test. An additional group of ewes was added to the straw lot and given 25,000 I.U. of vitamin A weekly in addition to the straw ration.

TABLE 1. RATIONS FED EXPERIMENTAL EWES

Straw lot—Low carotene ration

Before lambing		After lambing	
Oat straw	Free choice	Oat straw	Free choice
Grain mixture	1.00 lb.	Grain mixture	2.75 lb.
Oats	0.86 lb.	Oats	2.50 lb.
Soybean O.M	0.14 lb.	Soybean O.M.	0.25 lb.
$CaCO_3$	1.33 lb./100 lb. grain mixture	$CaCO_3$	1.33 lb./100 lb. grain mixture
Iodized salt	Free choice	Iodized salt	Free choice

Hay lot—Control ration

Before lambing		After lambing	
Alfalfa hay (with some grass)	3.0 lb.	Alfalfa hay (with some grass)	3.0 lb.
Oats	0.8 lb.	Oats	1.5 lb.
Iodized salt	Free choice	Iodized salt	Free choice

The ewes lambed in March. Immediately after lambing and before the lambs nursed, blood samples were collected from the jugular vein of the ewes and their lambs. Milk samples were collected from the ewes. Blood and milk samples were collected again when the lambs were 1 day, 4 days, 7 days, 1 month, and 2 months of age.

The blood was analyzed for blood plasma vitamin C by the method of Mindlin and Butler (1938) and for blood plasma vitamin A by the method of Kimble (1939). The milk was analyzed for vitamin C by the method of Woessner *et al.* (1939) and for vitamin A by the method of Boyer *et al.* (1944).

In 1947 approximately half of the ewes and lambs from each lot were sacrificed when the lambs reached 8 weeks of age. The vitamin A in the liver was determined by the method of Davies (1933).

Results and Discussion

The mean ewe blood plasma vitamin A values are given in table 2.[4] The ewes from the hay lot with one exception maintained a consistently higher mean blood plasma vitamin A level than did the ewes on the straw or straw-plus-vitamin-A rations. The administration of 25,000 I.U. of vitamin A weekly did not increase the blood plasma vitamin A level of the ewes. All ewes showed increased blood plasma vitamin A values at 4 days after parturition. This higher level was maintained throughout the lactation period.

TABLE 2. AVERAGE EWES' BLOOD PLASMA VITAMIN A LEVELS
γ/100 cc. PLASMA

Lot	Birth	1 da.	4 da.	7 da.	1 mo.	2 mo.
1946						
Hay	28.9 (7)†	30.0 (7)	35.7 (7)	34.6 (7)	38.7 (7)	31.0 (5)
Straw	21.8 (8)	22.0 (8)	28.7 (9)	25.6 (9)	29.2 (8)	26.7 (9)
P	<.05*	<.01**	>.05	<.05*	<.05*	>.05
1947						
Hay	26.8 (7)	24.3 (7)	32.0 (7)	34.9 (7)	38.4 (7)	35.8 (7)
Straw	24.2 (9)	27.3 (9)	30.6 (9)	31.2 (8)	28.5 (9)	27.2 (8)
Straw+vit. A	22.8 (6)	23.1 (6)	29.6 (6)	23.6 (6)	29.2 (6)	23.2 (6)
P	>.05	>.05	>.05	>.05	>.05	<.05*

† Number of animals averaged.
* Significant.
** Highly significant.

The average blood plasma vitamin A concentrations for the lambs produced by the ewes receiving these rations are given in table 3. All lambs were born with a very low level of vitamin A in the blood plasma. This level increased rapidly during the first day when the lambs received colostrum.

In 1946 the average values for the lambs at birth from the ewes in the hay and straw lots were very similar, but in 1947 the hay lambs had somewhat higher values than did the straw lambs. In 1946 the hay lambs maintained a consistently higher level of blood plasma vitamin A than did the straw lambs. This difference was very marked at the later bleedings. In 1947 the straw-plus-vitamin-A lambs showed the most rapid increase during

[4] Analysis of variance was run on these data using the F test (Snedecor, 1946). P is used in the tables to express the probability of differences of this size or larger occurring by chance alone. Differences are accepted as significant when P equals 1 per cent to 5 per cent shown by symbol <.05; as highly significant when P equals less than 1 per cent shown by the symbol <.01.

TABLE 3. AVERAGE LAMBS' BLOOD PLASMA VITAMIN A LEVELS
γ/100 cc. PLASMA

Lot	Birth	1 da.	4 da.	7 da.	1 mo.	2 mo.
			1946			
Hay	5.3 (10)†	14.8 (10)	18.8 (10)	18.7 (9)	25.0 (8)	29.6 (8)
Straw	5.4 (10)	14.3 (11)	15.9 (11)	14.0 (10)	16.2 (9)	13.6 (11)
P	>.05	>.05	>.05	>.05	<.01**	<.01**
			1947			
Hay	6.0 (11)	12.4 (10)	9.1 (10)	18.1 (10)	22.6 (9)	24.4 (8)
Straw	3.8 (15)	12.1 (13)	11.9 (12)	14.9 (11)	15.4 (10)	13.2 (10)
Straw+vit. A	2.3 (9)	17.0 (8)	16.0 (9)	12.6 (9)	16.5 (8)	16.1 (9)
P	>.05	>.05	<.05*	>.05	<.05*	<.01**

† Number of animals averaged.
* Significant.
** Highly significant.

the first 24 hours and had the highest level at the 4-day bleeding, but at the 7-day bleeding the hay lambs had the highest average blood plasma level. At the later bleedings the hay lambs had significantly higher levels of vitamin A in the plasma than did either the straw or straw-plus-vitamin-A lambs. The blood plasma vitamin A levels of the hay lambs continued to

TABLE 4. AVERAGE MILK VITAMIN A CONCENTRATIONS
γ/100 cc.

Lot	Colostrum	1 da.	4 da.	7 da.	1 mo.	2 mo.
			1946			
Hay	250 (6)†	91 (6)	56 (7)	25 (7)	27 (5)	
Straw	297 (5)	167 (8)	51 (9)	47 (8)	20 (7)	
P	>.05	>.05	>.05	>.05	>.05	
			1947			
Hay	293 (6)	179 (7)	65 (7)	46 (7)	42 (7)	41 (7)
Straw	333 (7)	196 (8)	64 (7)	38 (7)	27 (8)	23 (8)
Straw+vit. A	274 (4)	210 (5)	81 (6)	71 (6)	38 (6)	32 (6)
P	>.05	>.05	>.05	>.05	<.01**	<.01**

† Number of animals averaged.
** Highly significant.

increase with age, approaching the level of the mature ewes, whereas the straw and straw-plus-vitamin-A lambs did not increase appreciably after the initial colostral rise.

The average vitamin A concentration in the milk of the experimental ewes is shown in table 4. The colostrum of the ewes in all lots was high in vitamin A. The vitamin A concentration of the milk of all ewes dropped rapidly during the first week after parturition. After the ewes had been milking a few weeks, the hay group was consistently producing milk with the highest vitamin A concentration, the straw ewes were consistently producing milk of the lowest vitamin A potency. The later milk of the straw-plus-vitamin-A ewes was somewhat higher in vitamin A than was the milk of the straw ewes.

The vitamin A and carotene stores found in the livers of ewes and lambs killed about 8 weeks after lambing during the second season are given in table 5. Very low levels of carotene were found in all livers with slightly larger amounts in the livers of the ewes and lambs from the hay lot. The vitamin A stores in the liver of both the ewes and the lambs from the straw lot were distinctly lower than the stores in the livers of the hay lot ewes and lambs. The intermediate vitamin A liver stores of both the ewes and lambs from the straw-plus-vitamin-A lot indicate that the vitamin A given by capsule did influence the liver vitamin A reserves.

TABLE 5. AVERAGE LIVER VITAMIN A AND CAROTENE CONCENTRATION OF EWES AND LAMBS KILLED 8 WEEKS AFTER LAMBING—1947

Lot	Carotene γ/gm.	Vitamin A γ/gm. (wet wt.)	Vitamin A per liver mg./liver
Ewes			
Hay	1.7 (3)†	178.7 (3)	173.0 (3)
Straw	0.8 (5)	49.4 (5)	35.3 (4)
Straw+vit. A	1.0 (4)	115.9 (4)	86.9 (4)
P		<.01**	<.01**
Lambs			
Hay	1.0 (4)	60.4 (4)	19.8 (4)
Straw	0.6 (6)	6.9 (6)	1.9 (6)
Straw+vit. A	0.6 (5)	20.9 (5)	4.9 (5)
P		<.01**	<.01**

† Number of animals averaged.
** Highly significant.

The blood plasma ascorbic acid values obtained for the experimental ewes are shown in table 6. In 1946 the average values for the straw ewes were always lower than the average values for the hay ewes, but there was so much individual variation that the difference was significant only at the 7-day bleeding. In 1947 the mean values for the straw ewes were lower for the week following lambing but were comparable to the levels of the hay ewes at the later bleedings. The straw-plus-vitamin-A ewes had lower average values at the later bleedings but the difference reached significance only at the 4-week bleeding.

TABLE 6. AVERAGE EWES' BLOOD PLASMA VITAMIN C LEVELS
mg./100 cc. PLASMA

Lot	Birth	1 da.	4 da.	7 da.	1 mo.	2 mo.
			1946			
Hay	.66 (7)†	.59 (7)	.51 (7)	.51 (7)	.76 (5)	.62 (5)
Straw	.60 (8)	.48 (8)	.47 (9)	.35 (9)	.49 (5)	.51 (6)
P	>.05	>.05	>.05	<.05*	>.05	>.05
			1947			
Hay	.61 (7)	.51 (7)	.56 (7)	.54 (7)	.69 (7)	.74 (7)
Straw	.52 (9)	.47 (8)	.44 (9)	.40 (8)	.67 (9)	.70 (8)
Straw+vit. A	.52 (6)	.58 (6)	.46 (5)	.36 (6)	.38 (6)	.58 (6)
P	>.05	>.05	>.05	>.05	<.05*	>.05

† Number of animals averaged.
* Significant.

The mean blood plasma ascorbic acid values for the lambs are shown in table 7. The average values for the hay lambs were generally higher than the levels of the straw lambs, but again a large amount of individual variation was found. The straw lamb values in 1947 were considerably higher at the later bleedings than were the values for similar lambs in 1946. The lambs from the straw-plus-vitamin-A lot showed a more rapid increase in the blood plasma vitamin C level than did the lambs from the other two lots.

The concentration of vitamin C in the milk of the experimental ewes is shown in table 8. The large amount of individual variation in the small number of samples analyzed limits the significance of the differences found, but certain trends appear worthy of note. Both years the colostrum and early milk of the hay ewes contained higher concentrations of ascorbic acid than did the milk of the straw ewes during the same period. The colostrum

TABLE 7. AVERAGE LAMBS' BLOOD PLASMA VITAMIN C LEVELS
mg./100 cc. PLASMA

Lot	Birth	1 da.	4 da.	7 da.	1 mo.	2 mo.
			1946			
Hay	.29 (7)†	.23 (7)	.24 (7)	.31 (7)	.60 (4)	.57 (4)
Straw	.30 (7)	.21 (8)	.18 (8)	.21 (8)	.31 (6)	.34 (5)
P	>.05	>.05	>.05	>.05	<.01**	>.05
			1947			
Hay	.32 (11)	.33 (7)	.33 (9)	.45 (9)	.48 (9)	.68 (9)
Straw	.25 (16)	.20 (9)	.19 (12)	.28 (11)	.54 (10)	.59 (10)
Straw+vit. A	.29 (9)	.25 (6)	.35 (7)	.55 (9)	.58 (9)	.55 (9)
P	>.05	>.05	<.05*	<.01**	>.05	>.05

† Number of animals averaged.
* Significant.
** Highly significant.

TABLE 8. AVERAGE MILK VITAMIN C CONCENTRATIONS
mg./100 cc.

Lot	Colostrum	1 da.	4 da.	7 da.	1 mo.	2 mo.
			1946			
Hay	3.96 (7)†	4.10 (6)	2.84 (7)	3.01 (7)	4.34 (6)	—
Straw	1.94 (3)	3.08 (7)	2.12 (8)	2.03 (8)	3.30 (7)	—
P	>.05	>.05	>.05	>.05	>.05	—
			1947			
Hay	6.52 (6)	4.17 (7)	2.76 (7)	3.39 (7)	3.75 (7)	4.10 (7)
Straw	2.32 (5)	2.77 (7)	2.04 (8)	3.12 (9)	4.42 (8)	4.33 (8)
Straw+vit. A	3.95 (5)	4.00 (5)	4.38 (6)	4.57 (5)	5.13 (6)	6.22 (6)
P	>.05	>.05	<.05*	>.05	>.05	>.05

† Number of animals averaged.
* Significant.

of the straw-plus-vitamin-A ewes was intermediate in vitamin C content, but contained the highest concentration at later tests.

Table 9 shows the average ewe body weights during the periods they were fed the experimental rations. The group of ewes receiving the ration of alfalfa hay and some oats gained more weight during the gestation period and maintained heavier weights throughout the experiment than did the ewes receiving the ration of straw supplemented with soybean oil meal, calcium, and a larger allowance of oats. The group of ewes receiving 25,000 I.U. of vitamin A per week in addition to the straw ration lost slightly more weight than did the ewes receiving only the straw ration.

TABLE 9. AVERAGE WEIGHT OF EWES

1946

Lot		Dec. 12 1945	Jan. 22 1946	Feb. 22	Apr. 12	Wool wt.	June 10	Wt. loss†
		lb.	lb.	lb.	lb.	lb.	lb.	lb.
Hay		163.8 (9)*	171.7 (9)	181.9 (9)	160.8 (9)	8.6 (9)	150.5 (8)	4.7
Straw		162.9 (9)	165.2 (9)	171.4 (9)	149.1 (9)	7.7 (9)	128.9 (9)	26.3

1947

Lot	Nov. 13 1946	Dec. 13	Jan. 14 1947	Feb. 13	4 wk. after lambing	Wool wt.	8 wk. after lambing	Wt. loss†
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Hay	149.3 (7)*	163.7 (7)	170.7 (7)	183.9 (7)	154.9 (7)	7.9 (7)	140.3 (7)	1.1
Straw	141.3 (9)	147.4 (9)	149.3 (9)	152.9 (9)	133.0 (9)	6.2 (8)	127.0 (8)	8.1
Straw+vit. A	116.7 (6)	124.5 (6)	122.7 (6)	129.5 (6)	118.3 (6)	6.0 (6)	101.8 (6)	9.0

* Number of animals averaged.
† Initial weight—(final weight+wool weight).

TABLE 10. LAMB PERFORMANCE DATA

Lot	No. of ewes	No. of lambs born	% mortality up to 60 days	Wt. at 60 days, lbs.			Pounds of lamb at 60 days of age per cwt. of ewe		
				Singles	Twins	Triplets	Singles	Twins	Triplets
1946									
Hay	8	14	36.0	41.9 (4)*	35.0 (4)	—	26.2	44.4	—
Straw	9	15	27.0	42.9 (5)	23.9 (6)	—	26.7	28.3	—
1947									
Hay	7	12	25.0	53.3 (4)	34.4 (4)	27.5 (1)	31.1	50.8	15.1
Straw	9	16	37.5	46.6 (4)	24.3 (6)	—	30.0	33.1	—
Straw+vit. A	6	9	0	34.3 (3)	23.2 (6)	—	28.6	35.0	—

* Number of animals averaged.

The lamb production record of the ewes is given in table 10. The high mortality in 1946 is attributed in part to lambs becoming chilled before nursing, as the quarters were damp and cold. Two of the 3 hay lambs which died in 1947 were triplets. Low milk production of the straw ewes appeared to be responsible for at least part of the large lamb loss in this lot.

The single lambs from the straw ewes grew surprisingly well both seasons. The effect of the ration is reflected in the twin average weight and the pounds of twin lambs produced both years. The straw twins both seasons were thin, unthrifty lambs. The ewes receiving 25,000 I.U. of vitamin A weekly in addition to the straw ration did not produce any better lambs than did the ewes on the straw ration.

Discussion

Mature sheep have been shown to store large amounts of vitamin A in the liver (Peirce, 1946). Moore and Payne (1942) found less seasonal variation in the liver storage of vitamin A in sheep than in other classes of farm animals.

The quality of the winter roughage fed to ewes which have been on pasture during the summer, was found to influence the blood plasma vitamin A level and the liver vitamin A reserve of ewes and their lambs. Higher vitamin A concentrations were found in the later milk of the ewes fed alfalfa hay. These differences indicate that a good winter roughage is necessary for the maintenance of optimum vitamin A levels.

The ability of sheep to withstand extended periods on a low carotene ration was demonstrated by the ewes on the straw ration for two successive winters. While these ewes did not maintain as high a blood plasma vitamin A level or as high a liver vitamin A storage, these ewes did maintain blood plasma vitamin A levels above 20 γ per 100 cc. After milking for 8 weeks these ewes still maintained some reserve of vitamin A in their liver. The straw ewes produced colostrum of a high vitamin A potency but the low carotene intake was reflected in the low vitamin A concentration in the later milk. The ewes on this low carotene ration were able to produce satisfactory single lambs, but twin lambs did poorly. This poor growth rate of the twin lambs is attributed to a low milk production by the ewes on the straw ration as Shrewsbury *et al.* (1943) has reported a correlation of 0.89 between the amount of milk given by the ewe and the growth rate of her lamb.

The addition of 25,000 I.U. of vitamin A weekly to the straw ration was not reflected in the body weight of the ewes, the growth of the lambs, or the blood plasma vitamin A level of either the ewes or their lambs. The increased vitamin A intake was reflected in the vitamin A content of the later milk and the vitamin A liver stores of both the ewes and their lambs.

Summary and Conclusions

In order to study some of the effects of a low carotene ration on ewes and their lambs, a group of ewes was fed the following ration for two successive winters: oat straw, oats, soybean oil meal, and $CaCO_3$. A control group was fed alfalfa hay and oats. During the second season, additional ewes were added to the low carotene group and given 25,000 I.U. of vitamin A weekly.

Blood plasma vitamin A levels of the ewes and their lambs receiving the hay ration were consistently higher than the plasma vitamin A levels of the ewes and lambs receiving the straw ration with or without the addition of 25,000 I.U. of vitamin A weekly.

The vitamin A concentration of colostrum was high in all lots, with no appreciable differences between lots during the first week after parturition. The vitamin A concentration of the later milk from the hay lot ewes was significantly higher than the later milk from the straw lot ewes. The straw-plus-vitamin-A ewes produced milk of intermediate vitamin A concentration.

The liver vitamin A stores of ewes and lambs killed 8 weeks after lambing, in the second season, were found to be much higher in the ewes and lambs on the hay ration than in the ewes and lambs on the straw ration. The liver stores of the ewes and lambs from the straw-plus-vitamin-A group were somewhat higher than the levels found in the straw group, but were still low.

Considerable individual variation was encountered in the blood plasma ascorbic acid values. The mean plasma ascorbic acid values for the ewes were generally lower for the straw and straw-plus-vitamin-A ewes than for the hay ewes. While the effect of the ration on the lamb blood plasma vitamin C was not consistent, the lambs from the straw lot were generally low in this respect.

Small numbers and large individual variation limit the significance of the milk ascorbic acid values. Average values for the colostrum and early milk from the hay ewes were higher than those from the straw ewes. The colostrum from the straw-plus-vitamin-A ewes contained an intermediate level of ascorbic acid and the highest amounts in the later milk.

The hay ewes maintained heavier body weights during the experiment than did the straw or straw-plus-vitamin-A ewes.

The growth rates of the single lambs from the hay and straw lots were quite similar. The growth rate of the single lambs from the straw-plus-vitamin-A lot was somewhat slower. Twin lambs from the hay lot grew markedly better than did the twin lambs from the straw and straw-plus-vitamin-A lots.

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CAUSES AND CERTAIN FACTORS AFFECTING LAMB MORTALITY[1]

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LAMB mortality during the first few weeks after birth results in a considerable loss to sheepmen. Bell (1947) observed that of 1,702 fetuses delivered during a ten year period, 328 died before reaching the age of two months. This figure included premature births and still-born lambs carried full time. He reported an average mortality rate of about 19 percent. "Poor mothering and lack of milk" was given as the most important cause of death. It is believed that more information on the causes of death in young lambs will aid sheepmen in overcoming these losses.

Records Analyzed

The records of 483 lambs from 312 pregnancies were studied. These lambs were born in the Michigan State College flock during the years 1945–1947. The flock contained six breeds: Shropshire, Hampshire, Oxford, Rambouillet, Southdown and Cotswold. These breeds were all fed and cared for under similar conditions, and management practices were kept as uniform as possible from year to year. Complete breeding and lambing records have always been kept on the flock. Beginning in 1945, complete autopsies have been made on all lambs that died.

The records were studied to determine the relative importance of the various causes of death of young lambs and the effect of year, breed, sex, type of birth, birth weight and inbreeding on lamb mortality. This study deals with mortality of lambs up to two months of age since about 95 percent of the deaths occurred during that period.

Results and Discussion

Causes of Lamb Mortality

The relative importance of the various causes of death is summarized in table 1. Of the 483 lambs dropped, 138 or 28.6 percent died before reaching two months of age. About 71 percent of these died during the first two weeks.

Pneumonia was responsible for almost one-third of the deaths. It was observed from the autopsy reports that many of the lambs that died of pneu-

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monia showed patency of the foramen ovale (open heart valve). It was believed that a lamb whose foramen ovale did not close soon after birth might possibly be more susceptible to pneumonia than one with a normal foramen ovale. Therefore, the lambs that died of pneumonia were divided into two classes: (a) Those with normal foramen ovale of the heart and (b) Those with foramen ovale still open at the time of death. These two classes consisted of 64 percent and 36 percent respectively of the lambs that died of pneumonia. It is not definitely known how long the foramen ovale can remain

TABLE 1. IMPORTANCE OF THE VARIOUS CAUSES OF LAMB MORTALITY

Cause of death	Lambs that died of each cause	
	No.	Percent
Pneumonia	42	8.7
Premature births	18	3.7
Weak lambs	14	2.9
Still-births (carried full time)	11	2.3
External abnormalities	10	2.1
Internal abnormalities	7	1.4
Other diseases	9	1.9
Miscellaneous	19	3.9
Undetermined	8	1.7
Total	138	28.6

open after birth without any ill effect on the lamb. The condition of patency of foramen ovale has, in this study, been recorded as late as 55 days of age in a lamb that died of pneumonia. Normally, it closes soon after birth. In lambs, the closure of the ductus arteriosus normally follows the closure of the foramen ovale of the heart (Barclay *et al.*, 1945), but the reverse has been recorded in these autopsies. That is, when the ductus arteriosus was well obliterated the foramen ovale remained open and showed no tendency to close. Thirty-eight percent of the lambs that died of pneumonia after four days of age showed the open foramen ovale. This figure is not significantly different from the 29 percent open foramen ovale found in lambs that died of causes other than pneumonia after four days of age. It does not appear that this condition predisposed lambs to pneumonia. However, further study should be made on the effect of patency of the foramen ovale.

External and internal abnormalities were physical defects which resulted in the death of the lambs. They included such things as parrot mouth, cyclops, five-legs, monstrosity (monster head), mummified fetus, malformed liver, and umbilical hernia. These physical defects accounted for a loss of 3.5

percent of the lambs born or 12 percent of the entire death loss. These causes of death are likely controlled more completely by heredity than any of the other causes of death listed in the table. They could be classed as lethal or semi-lethal factors and are probably controlled by one or two gene factor pairs. An example of this is the two cases of parrot mouth born in Cotswold flock in 1945. These two lambs were the result of sire-daughter matings. This ram was also mated to two of his other daughters and resulted in the birth of normal lambs. If this trait is inherited as a simple recessive, a ratio of one parrot mouth to seven normal would be expected from this type of mating, providing the ram were the only source of this gene. The higher ratio obtained here is entirely possible in the small sample observed and it might also have resulted from this gene coming in from the maternal as well as the paternal line.

Contagious abortion was not responsible for any of the premature births. A large percent of these premature births were known to have occurred following things such as shearing, crowding through narrow gates or doors, etc. Still-births carried full time were made up largely of lambs that were dead because of difficulty at parturition. Weak lambs included those that were unable to get up and move around by themselves and were probably the result of nutritional deficiencies in-utero.

Other diseases include death from bacteraemia, navel infection and coccidiosis. There was only one case each of navel infection and coccidiosis. The miscellaneous group included accidents and overconsumption of milk; the accidents consisted of such things as overlaying, trampling, drowning and haemorrhage around the urinary bladder.

Influence of Various Factors on Lamb Mortality

Year

The records for the three years (1945, 1946 and 1947) were studied. The mortality rate for these three years was 37 percent, 26 percent and 27 percent respectively. In 1945, the year of highest mortality, pneumonia resulted in twice as large a death loss as in each of the two succeeding years. This probably accounts for the higher overall mortality rate found in 1945. However, the difference in mortality rate beween years was not statistically significant. Therefore, the records were analyzed as one set of data for the remainder of the study.

Breed

The mortality rate in the different breeds is given in table 2. There was quite a striking difference in mortality in the six breeds kept in this flock. The three heavier breeds showed a distinctly higher loss than the three

lighter breeds. These differences were statistically highly significant. Even when analyzed on a yearly basis the same three breeds (Cotswold, Oxford and Hampshire) consistently showed a higher mortality rate.

TABLE 2. LAMB MORTALITY IN DIFFERENT BREEDS

Breed	No. of pregnancies	No. of lambs born	No. of lambs died	Percent mortality at two months
Cotswold	22	33	14	42.2
Oxford	46	75	29	38.6
Hampshire	76	120	46	38.3
Southdown	20	34	7	20.6
Shropshire	110	160	31	19.4
Rambouillet	38	61	11	18.0
Total	312	483	138	28.6

Sex

Of the 479 lambs born with sex recorded 268 were ram lambs and 211 ewe lambs, a sex ratio of 56 percent males to 44 percent females. The mortality rate for ram lambs was significantly higher than that for ewe lambs, the former being about 34 percent and the latter 24 percent. This difference in death rate resulted in tendency to balance the sex ratio as the lambs got older. At eight months of age there were approximately 52 percent males and 48 percent females.

Type of birth

The records showed that about 50 percent of the births were multiple births. The rate of twinning varied from a high of 70 percent for the Southdowns to a low of 43 percent for the Shropshires, with the other four breeds being quite uniform and intermediate between these two. The rate of mortality was significantly higher in multiple births than in single births, the former being 35 percent and the latter 20 percent.

Birth Weight

The effect of birth weight on lamb mortality was studied on an intra-breed basis. A table was set up in which the birth weight of each lamb was recorded as the deviation from its breed average. Table 3 shows the distribution of the deviations. The average birth weights and standard deviations are shown in table 4. An interesting point in regard to these birth weights was the smaller amount of variation found in weights of Ram-

bouillets and Southdowns as compared with the other four breeds. It was found that within breeds there was a significantly higher mortality among the lighter lambs.

TABLE 3. EFFECT OF BIRTH WEIGHT ON LAMB MORTALITY

Items compared	Deviation from breed mean												
	−6	−5	−4	−3	−2	−1	0*	1	2	3	4	5	6
No. of births	5	6	12	28	47	80	106	85	51	35	11	6	3
No. of deaths	5	4	9	13	20	18	30	17	11	10	2	1	2
Percent mortality	100.0	66.6	75.0	46.4	42.5	22.5	28.3	20.0	21.5	28.5	18.2	16.6	66.6

* Mean birth weight of the various breeds.

TABLE 4. AVERAGE BIRTH WEIGHTS OF VARIOUS BREEDS

Breed	Mean birth weight in pounds	Standard deviation
Cotswold	10.3±0.47	2.7±0.33
Oxford	9.2±0.28	2.5±0.20
Hampshire	9.6±0.21	2.4±0.15
Southdown	7.2±0.25	1.5±0.18
Shropshire	8.1±0.19	2.5±0.13
Rambouillet	8.8±0.11	0.9±0.08

Inbreeding

The coefficient of inbreeding was calculated for each lamb that died of a possible inherent cause. The average inbreeding of these lambs for each breed is shown in table 5. The Rambouillets, the breed with the lowest mortality, were the only ones that showed a significant amount of inbreeding. The average coefficient of inbreeding was 15 percent for the Rambouillet lambs

TABLE 5. INBREEDING AND MORTALITY OF LAMBS THAT DIED OF POSSIBLE INHERENT CAUSES

Breed	Total No. of lambs	No. of lambs died	Percent died	No. of inbred	Average percent of inbreeding
Cotswold	33	6	18.1	2	8.3
Oxford	75	13	17.3	3	2.5
Hampshire	120	25	20.8	6	3.5
Southdown	34	5	14.7	1	5.0
Shropshire	160	22	13.7	1	0.1
Rambouillet	61	8	13.1	8	15.0

that died and 17 percent for those that survived. Apparently inbreeding had no effect on mortality in the Rambouillet breed. From table 5, it will be observed that the majority of the lambs that died in the other breeds were not inbred. Apparently, inbreeding has not been an influencing factor on the lamb mortality in this flock.

Summary

The autopsy reports of 138 lambs of the Cotswold, Hampshire, Oxford, Rambouillet, Shropshire and Southdown breeds were analyzed to determine the relative importance of the various causes of death of young lambs. The flock records were studied to determine the effects of year of birth, breed, sex, type of birth, birth weight of lamb and percent of inbreeding on mortality rate up to two months of age.

The results show that both heredity and environment are important factors in young lamb mortality. The principal causes of death in this flock were pneumonia, premature births, weak lambs, still-births (carried full time) and external and internal abnormalities. Factors which had an effect on lamb mortality were breed, sex, type of birth and birth weight. A higher mortality rate was observed in the larger breeds. There was a higher mortality in males and twins than in females and single lambs respectively. Lambs much below the breed average in birth weight had very little chance of survival. Year of birth and inbreeding were not important contributing factors to lamb mortality in this flock.

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INITIAL PHYSICAL AND CHEMICAL CHANGES IN BEEF AS RELATED TO TENDERNESS[1]

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BEEF which has been stored for two to four weeks at temperatures between 32° and 40° F., or for a few days at somewhat higher temperatures up to 68° F., is generally classified as commercially aged beef.

There is a wealth of information on the progressive improvement of tenderness during the interval from one day following slaughter to four weeks following slaughter; however, there is very little information on the initial tenderness of the beef at the time of slaughter as related to the tenderness of chilled, aged, and frozen beef.

The purpose of this study was to develop information on the tenderness and other characteristics of beef at frequent intervals from two hours following slaughter to twelve days following slaughter. Similar studies were made on beef frozen at intervals during the twelve-day period, having been held at 35° F. from the time of slaughter to the time of freezing. The relationship of boning beef before chilling to tenderness was investigated in another phase of the study.

Methods

Beef carcasses were selected at the time of slaughter. The grades and weights of the carcasses together with the treatment of the loins and steaks are outlined in table 1.

In an earlier study (Ramsbottom, Strandine and Koonz, 1945) the longissimus dorsi muscle was indicated to be fairly uniform in tenderness except at the extremities. In addition this muscle makes up a large portion of all loin steaks and rib roasts; therefore, it was selected for this study. The longissimus dorsi muscle was not removed as such, but rather as part of the entire loin including the adjoining muscles and cover fat located between the ninth thoracic vertebra and the fifth lumbar vertebra. In trade circles, this unit is described as a boneless loin or boneless strip. Tests were made on steaks cut one inch in thickness at intervals of 2, 5, 8, 11 and 14 hours also 1, 2, 3, 6, 9, and 12 days following slaughter.

Carcasses 1 to 4 were used to study the effect of dissection of the muscles at the time of slaughter on the quality of the beef. Carcasses 5 to 10 were used to obtain information on the initial tenderness of the beef, also on the

[1] This paper was presented at the fortieth annual meeting of the American Society of Animal Production, November 27, 1948, Chicago, Illinois.

TABLE 1. OUTLINE OF PROCEDURE FOR TESTING BEEF

Carcass data			Treatment of loins		Treatment of steaks		
Identification	Grade	Dressed weight (lbs.)	Boneless loin removed from beef side at time of slaughter and chilled to 35°F.	Chilled as side of beef to 35°F. boneless loins cut 48 hrs. after slaughter	Steaks cut and tested at intervals of 3, 6, 9 and 12 days following slaughter	Steaks cut and tested at intervals of 2, 5, 8, 11, 14 hrs. and 1, 2, 3, 6, 9 and 12 days following slaughter	Steaks cut and frozen at intervals of 2, 5, 8, 11, 14 hrs. and 1, 2, 3, 6, 9 and 12 days following slaughter. Thawed and tested 2 weeks later
(1) Heifer	Choice	503	L*	R*	R* and L*		
(2) Heifer	Choice	523	R	L	R and L		
(3) Cow	Commercial	549	L	R	R and L		
(4) Cow	Commercial	582	R	L	R and L		
(5) Heifer	Good	582	R and L			R	L
(6) Heifer	Good	568	R and L			L	R
(7) Heier	Good	587	R and L			R	L
(8) Cow	Utility	656	R and L			R	L
(9) Cow	Utility	479	R and L			L	R
(10) Cow	Utility	464	R and L			R	L

* Right and left side of beef carcass.

quality of beef frozen immediately following slaughter. As shown in table 1 the steaks from one side of carcasses 5 to 10 inclusive, were frozen at a temperature of −20 F., immediately after cutting. They were stored at this temperature for two weeks, then thawed and cooked. Steaks from the other side of the carcasses were cooked directly after being cut from the loins.

In order to obtain uniformity in cooking time and temperature and to bring out maximum differences in tenderness, the steaks were deep-fat cooked in lard, which was kept at a constant temperature of 250°F. Thermometers were inserted in the meat and each steak was removed from the lard upon reaching an internal temperature of 170°F.

The Warner-Bratzler shear (1928) was used to obtain shear readings on the cooked meat. Six one-half inch cylindrical samples were taken from each steak parallel to the fibers and were sheared across the fibers. The temperature of the cooked meat when sheared was 75 to 85°F. An average of the six readings was obtained for each steak. An adjoining steak was evaluated organoleptically for tenderness, texture, flavor and juiciness. Data were obtained on the temperature, color and pH of the raw beef.

The relationship between the color of beef and the pH of the beef was established in studies started in 1938 by the National Life Stock and Meat Board Committee on the Chemistry of Dark Cutting Beef (1949). In the present study Munsell color readings were made on the beef at frequent intervals during the first two days following slaughter. The readings were made on the cut surface one-half hour after cutting. Munsell beef color charts range in color from a very bright red which is given a numerical reading of (1) to a very dark red which is given a numerical rating of (10).

Histological studies were made on both the raw and cooked beef. Small pieces of raw beef were fixed in 10 percent formalin, dehydrated in alcohol, embedded in paraffin, and sectioned. Weigert's elastic tissue stain was used to show the distribution of the elastic connective tissue while Mallory's triple connective tissue stain was employed to demonstrate principally the collagenous connective tissue. From the cooked muscles, larger samples of muscle (approximately 3/4 by 1-1/2 inches) were sectioned on the freezing microtome and stained with gentian violet and Sudan III to show general histological patterns of the lean and fatty tissue.

Experimental Results

The Effect of Boning Beef Before Chilling on the Quality of the Beef

One of the expected results of chilling beef in the form of boneless cuts rather than as sides of beef should be a faster rate of chilling. This was confirmed in tests made on two "choice" grade carcasses and two "commercial"

grade carcasses. The chilling curves for the choice carcasses are shown in figure 1. It will be observed that the internal temperature of the longissimus dorsi muscle rose from about 100°F. immediately after slaughter to 102°F. one hour later, then dropped quickly when the carcasses were moved to a chilling cooler where the ambient temperature averaged 35°F.

The boneless loin section of one side of each carcass was dissected about one hour following slaughter. The temperature in the boneless loin section

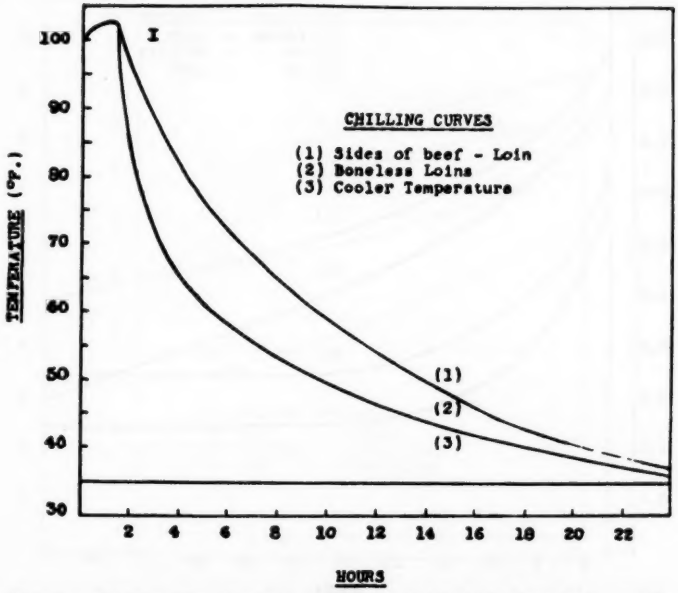


Figure 1. Chilling curves for choice quality beef. (1) sides of beef—temperature taken in longissimus dorsi muscle of loin (2) boneless loins—temperature taken in longissimus dorsi muscle of loins dissected from the sides of beef about one hour after slaughter (3) average ambient temperature.

(longissimus dorsi muscle) dropped more rapidly than the temperature of the loin in the companion side of beef. The maximum difference in temperature occurred two to eight hours following slaughter, when the temperature of the boneless loins was from 10 to 15 degrees lower than that of the control bone-in loins. By the twenty-fourth hour following slaughter the temperature of both the test and control beef had dropped below 40°F.

The chilling of the meat was accompanied by chemical changes in the muscles. One of the most significant of these changes was the hydrolysis

of the glycogen in the muscle to sugars and finally to lactic acid. The progress of this change is shown in figure 2, the pH value being a measure of the increasing acidity of the beef during the first 24 hours after slaughter. The pH of the beef dropped from about 6.4 at two hours after the dressing operation to about 5.5 one day later. The ultimate pH of the "utility" or common grade beef loins was consistently about two-tenths of a pH number higher than that of good grade loins.

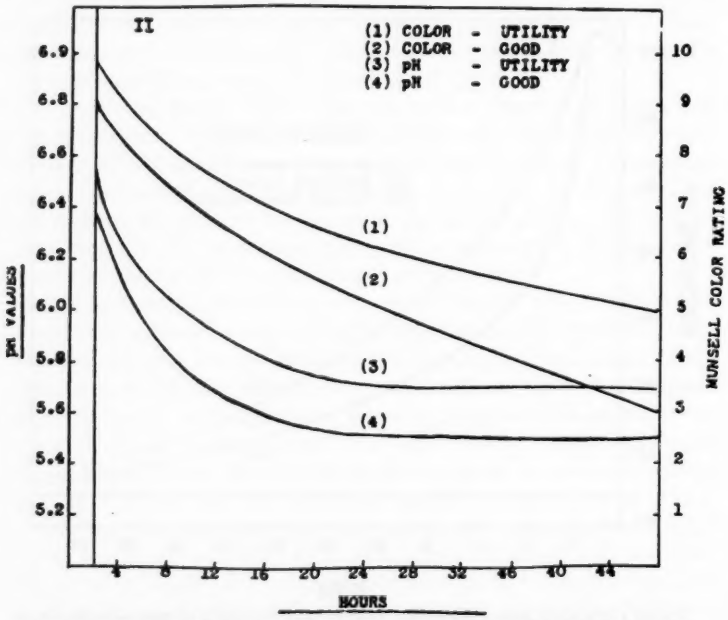


Figure 2. Progressive changes in the pH and color of good and utility quality beef during the first two days following slaughter.

Average color data on three good and three utility quality carcasses are presented in figure 2, along with the pH data. It will be observed that the color curves follow the pH curves. The change in the pH of the good quality beef from 6.4 to 5.5 was correlated with a change in the color from a very dark red to a bright red. The color of the utility or common grade beef at 48 hours after slaughter was about two grades darker than that of the good quality beef.

The effect of boning beef before chilling on the tenderness of the beef is shown in figures 3 and 4. Steaks cut from the longissimus dorsi muscles at

3, 6, 9, and 12 days, dating from the time of slaughter were broiled and rated for tenderness. These data are presented in figure 3. In addition, adjoining cooked steaks were sampled with a one-half inch cylinder and the samples were sheared with a Warner-Bratzler shear to obtain an objective measure of tenderness (figure 4).

Muscles which were dissected from sides of beef before they were chilled were less tender than those which remained intact in the side of beef until

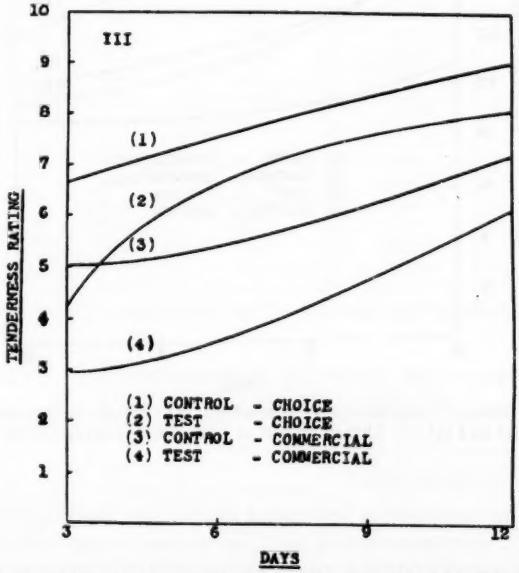


Figure 3. Tenderness rating of longissimus dorsi muscles. (a) Chilled as part of beef sides—curves (1) and (3). (b) Chilled as boneless loins—curves (2) and (4).

it was chilled. This tenderness difference lessened somewhat during the test. However, the beef which was chilled in sides was still considerably more tender by the twelfth day than the beef which was boned before it was chilled. It is suggested that the modification in chemical and physical changes brought about by boning the beef before chilling was responsible for this difference in tenderness. Also, the stimulation of muscle and nerve cells by cutting shortly after slaughter may be a factor influencing tenderness. As might be expected the choice quality beef was more tender than the commercial quality beef.

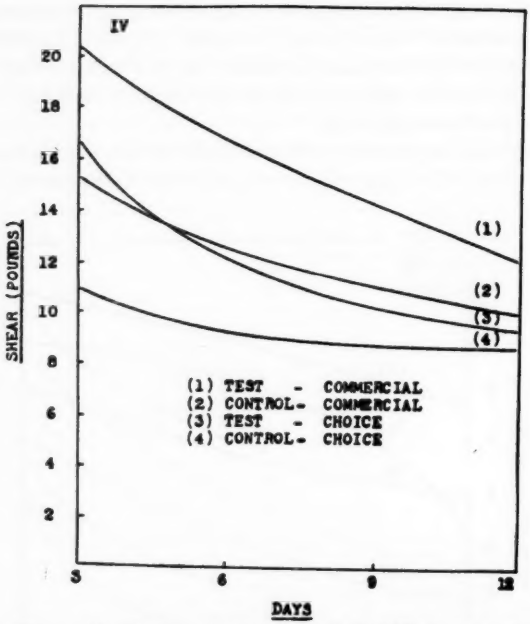


Figure 4. Shear of longissimus dorsi muscles. (a) Chilled as boneless loins curves (1) and (3). (b) Chilled as part of beef sides—curves (2) and (4).

Changes in Tenderness of Beef

Data on the tenderness of beef cooked directly after slaughter and of beef aged up to 12 days before cooking are reported in tables 2 and 3. In addition, these tables record tenderness values obtained on steaks which were stored in the freezer for two weeks, then thawed and cooked. Both tables show that the beef was more tender at two hours after slaughter than at two days after slaughter; however, there are variations in the time required for this trend toward toughness to be reversed and for the meat to become more tender than it was two hours after slaughter. Freezing and thawing the beef tended to mask the marked changes in tenderness which occurred in the unfrozen beef. This may be explained in part by observations made on beef frozen two hours following slaughter. The beef had a pH of 6.6 before being frozen at −20°F. After two weeks storage at −20°F., the temperature of the beef was raised slowly to 26°F. At this stage of thawing the pH was 6.4. The samples were held at room temperature (75°F.). One-half hour and one hour later pH values of 5.8 and 5.5 respectively were obtained, thus indicating

TABLE 2. SHEAR OF COOKED BEEF AS RELATED TO STORAGE TIME AND FREEZING

Time between slaughter and cutting of steaks	Average shear readings on cooked steaks*			
	Three good carcasses		Three utility carcasses	
	Cooked directly after cutting (lbs.)	Frozen two wks. then thawed and cooked (lbs.)	Cooked directly after cutting (lbs.)	Frozen two wks. then thawed and cooked (lbs.)
2 hours	15.2	17.3	13.4	17.5
5 "	20.1	18.6	16.3	18.6
8 "	20.9	18.9	17.3	18.4
11 "	19.6	17.8	21.2	19.2
14 "	20.2	18.1	22.1	18.8
1 day	20.5	18.9	20.8	21.8
2 days	17.0	18.0	21.5	21.6
3 "	14.1	16.5	23.9	20.1
6 "	10.1	15.3	20.7	17.9
9 "	12.3	14.6	16.2	15.5
12 "	10.1	13.5	16.7	14.5

* Each number is an average of eighteen tenderness determinations made with a Warner-Bratzler Shear.

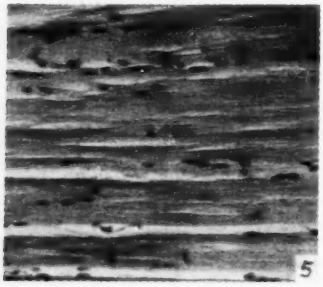
TABLE 3. TENDERNESS RATING OF COOKED BEEF AS RELATED TO STORAGE TIME AND FREEZING

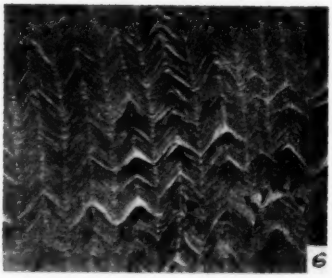
Time interval between slaughter and cutting of steaks	*Average tenderness rating on broiled steaks			
	Three U. S. good carcasses		Three U. S. utility carcasses	
	Cooked directly after cutting	Frozen two wks. then thawed and cooked	Cooked directly after cutting	Frozen two wks. then thawed and cooked
2 hours	5.7	5.7	5.8	4.8
5 "	4.5	4.5	5.3	4.2
8 "	3.8	4.8	5.3	4.2
11 "	3.2	5.2	2.8	3.8
14 "	3.5	5.2	3.1	4.5
1 day	3.5	5.2	2.7	3.3
2 days	5.3	5.6	2.0	3.8
3 "	6.0	6.0	2.0	3.0
6 "	8.5	6.7	3.0	3.8
9 "	8.3	6.7	4.5	4.8
12 "	8.5	7.5	6.0	6.3

* Tenderness rating—1—Extremely poor, 2—Very poor, 3—Poor, 4—Slightly poor, 5—Borderline minus, 6—Borderlin: Plus, 7—Slightly Good, 8—Good, 9—Very good, 10—Excellent.
Each number is an average of nine organoleptic tests.

a more rapid change in pH than observed for beef which was not frozen (figure 2).

Observations were made on the texture, flavor and juiciness of the cooked beef as related to storage before cooking. When examined at two hours after slaughter the muscle bundles in the cooked state were not hard or tough; however, they were closely bound together. By the fifth hour following slaughter, the bundles were hard and tough. This condition remained for one to two days. Then there was a gradual softening and loosening of the bundles, which was quite noticeable by the twelfth day. These changes





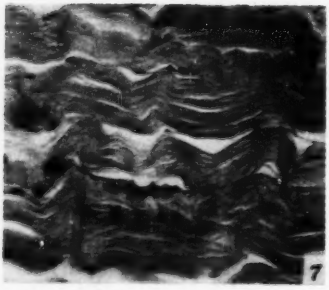


Fig. 5. Raw beef muscle fibers at an interval of 2 hours following slaughter. (187×)

Figure 6. Raw beef muscle fibers at an interval of 14 hours following slaughter. (187×)

Figure 7. Raw beef muscle fibers at an interval of 24 hours following slaughter. (187×)

Figure 8. Raw beef muscle fibers at an interval of 12 days following slaughter. (187)

in texture occurred earlier in good beef than in utility quality beef, and they were not so clearly defined in beef that had been frozen.

The flavor of both good and utility grade beef was quite bland when tested at two hours after slaughter. There was little change in the flavor for a day or so, then there was a gradual increase in flavor intensity which was quite noticeable when comparisons were made of beef stored for 2 hours and for 12 days from the time of slaughter.

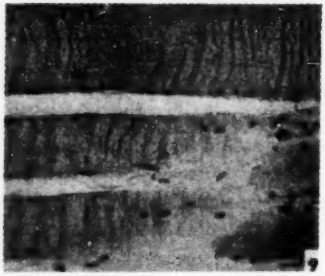
The juiciness of the beef did not seem to change significantly during the twelve-day test period. The good quality beef was voted more juicy than the utility or common beef.

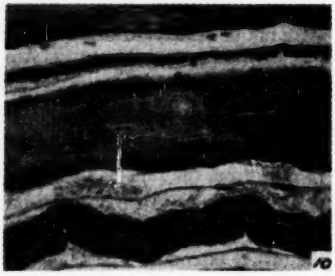
Histological Characteristics of Beef Tested at Intervals From Two Hours to Twelve Days Following Slaughter

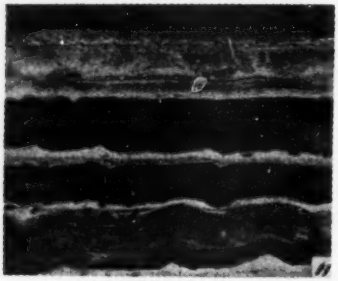
The histological characteristics of beef steaks cut at frequent intervals between the second hour following slaughter and the 12th day following slaughter are shown in figures 5 to 12. During the first few hours following slaughter in the early period, the muscle fibers were straight or slightly wavy (figure 5). This may be described as the pre-rigor period, and it varied in length from carcass to carcass.

Following the pre-rigor period, hard lumps began to appear in the muscle and eventually involved the whole muscle. Microscopic examination of the tissues in these lumps showed that the muscle fibers had been thrown into many sharply defined waves resembling a washboard in appearance (figure 6). This condition of the fibers is associated with rigor, beginning between 8 to 24 hours after slaughter and continuing until 24 to 72 hours after slaughter. Occasionally rigor began even earlier. During this period the shear reading of the cooked muscle was much higher than in the pre-rigor or post-rigor stages. Following the period of compact muscular contraction during rigor, the muscle began to soften and relax. Microscopically, this was associated with a loss of waviness so that almost all of the fibers appeared straight (figure 7). In some pieces of meat, the waviness of some individual fibers persisted even after 12 days. During this post-rigor period, the shear readings of the meat became lower.

Finally, after 8 to 12 days, there was a gradual and progressive breakdown of the muscle fibers brought about by enzyme action or autolysis. The muscle fibers broke transversely and longitudinally (figure 8), the ends of the muscle fibers, endomysium, and connective tissue disintegrating to various degrees. The nuclei of the various tissues appeared to be more resistant to autolysis. The breakdown of the muscle fibers and connective tissues which was observed histologically was reflected in lower shear readings and higher tenderness ratings by the twelfth day after slaughter.







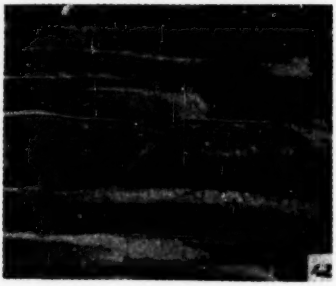


Figure 9. Cooked beef muscle fibers at an interval of 2 hours following slaughter. (187×)

Figure 10. Cooked beef muscle fibers at an interval of 14 hours following slaughter. (187×)

Figure 11. Cooked beef muscle fibers at an interval of 24 hours following slaughter. (187×)

Figure 12. Cooked beef muscle fibers at an interval of 12 days following slaughter. (187×)

Histological studies were made on the cooked beef. Muscle fibers in meat cooked shortly after slaughter showed peculiar transverse markings which may have been the remains of the broken-down myolemma or the endomysium (figure 9). This was not found in meat held for longer periods of time.

The waviness of the muscle fibers of cooked beef paralleled that of the raw meat, although in some cases where the raw meat had many sharp waves, the waves were reduced in number or were absent in the cooked muscle (figure 10). There was an increasing amount of granular protein material between the muscle fibers in all beef cooked from one to twelve days following slaughter (figures 11 and 12). During cooking both longi-

tudinal and transverse breaks occurred in the muscle fibers, and at these points greater breakdown of the muscle fiber resulted (figure 12).

Collagenous fibers when cooked underwent first a swelling then a shrinkage and disintegration. During cooking, chemical changes occurred in the collagenous fibers as evidenced by the changes in their affinities for dyes. Collagenous fibers in cooked meat stained blue with Weigert's elastic connective stain while in fresh meat these fibers were not colored by this stain.

Steaks which were frozen at intervals from 2 hours after slaughter to 12 days after slaughter were sampled for histological study in the frozen state. When steaks were frozen at −20°F. about two hours after slaughter small intrafiber crystals formed which gave the meat a pale red appearance. As the interval between slaughter and freezing increased, the size of the ice crystals in the frozen meat increased. Beef steaks which had been frozen at −20°F. on the twelfth day after slaughter were dark red primarily because the ice crystals were large and located outside the muscle fibers. These observations confirmed studies reported previously by Ramsbottom and Koonz, 1940. The autolytic changes which occur in the meat during storage at 35°F. breakdown the meat histologically and chemically. Consequently, the ice crystal structure of the meat frozen after it has been aged is quite different from that of meat which has not been aged.

Summary

A study was made to develop information on the initial tenderness of beef and to determine the relationship of some physical, chemical, and histological changes in the beef to changes in tenderness during a twelve-day period following slaughter. Experiments were made on ten beef carcasses which ranged in quality from common to choice.

Objective and subjective measurements of tenderness showed that beef which was chilled in carcass form was more tender than beef which was boned and then chilled to 35°F.

Beef was found to be more tender at two hours following slaughter than at any time thereafter for the next two to six days. By the twelfth day following slaughter, beef which was stored at 35°F. was considerably more tender than it was at two hours after slaughter. Beef which was frozen two hours following slaughter was lighter in color in the frozen state and darker in the thawed state than beef which was chilled for 24 hours or more before freezing.

Photomicrographs show that marked changes occurred in the histological characteristics of the muscle fibers. These changes were correlated with changes in the tenderness of the beef.

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EFFECT OF ADDING DRUGS TO THE RATION OF FATTENING CATTLE[1]

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THE so called "stimulant" drugs have been used in the fitting of cattle for shows and sales in the belief that they produce faster gains and a more abundant and glossy hair coat. Because the active ingredients of these drugs are toxic, many stockmen have questioned whether injurious effects may not follow their usage in cattle rations. Since the cattle fitted for shows and sales usually represent the better individuals of the various breeds, any injurious results obtained from the use of drugs would have far-reaching effects.

Astwood (1943) found that the reduction of thyroid activity by the administration of thiouracil resulted in a return to normal of the basal metabolic rate and was often followed by an increase in the body weight in the human. Conceivably, hypothyroidism, a condition associated with a decrease in metabolic rate and with obesity, might be desirable in animals being fattened for market, particularly if greater efficiency of feed utilization were also obtained.

Andrews and Bullard (1940), and Bullard and Andrews (1943) found that following partial thyroidectomy of beef steers the rate of gain was greatly increased during the first six to eight post-operative weeks, gradually decreasing and approaching normal after ten to twelve weeks.

Astwood (1943*a*), Astwood *et al.* (1943, 1945), MacKenzie and MacKenzie (1943), Kennedy (1942), Richter and Clisby (1942), Smithcors (1945), and McGinty and Bywater (1945), have demonstrated that a large number of compounds related to thiourea cause a decrease in the thyroxine secretion, a lowering of the basal metabolic rate, and a hyperplasia and hypertrophy of the thyroid glands in rats. Thiouracil and other goitrogenic agents probably exert their effect directly on the thyroid (Dietrich and Beutner 1944, Malkiel, 1946; and Goldsmith *et al.*, 1944).

The feeding of thiouracil to broilers has resulted in a marked improvement in market quality (Kempster and Turner, 1945; Andrews and Schnetzler, 1946; Andrews and Bohren, 1947). Work by Schnetzler *et al.* (1945) showed

[1] Published as Scientific Paper No. 800, College of Agriculture and Agricultural Experiment Station, Institute of Agricultural Sciences, State College of Washington, Pullman, Washington.

[2] Division of Animal Husbandry, Dr. R. W. Dougherty, College of Veterinary Medicine performed the biopsy sampling. This work was supported in part by grant funds from the Carstens Packing Company, Tacoma, Washington.

that thiouracil increased the daily gains of chickens, and apparently had no effect on market quality. Glazner and Jull (1946) found the dressed appearance of thiouracil treated birds to be less desirable than the controls.

Beeson, Andrews, and Brown (1947) reported that thiouracil fed to yearling steers at the rate of 2.0 to 6.0 grams daily for 154 days did not affect the growth of the animals and the rate of gain was slightly increased when 2.0 and 4.0 grams of the drug was fed. Feed efficiency and carcass quality was not significantly affected by the feeding of thiouracil. The feeding of thiouracil to fattening lambs did not affect the rate of growth (Andrews *et al.*, 1947). No differences in dressing percentage were noted, however the carcass quality was improved by the feeding of 0.175 grams and 0.333 grams of thiouracil daily. Muhrer and Hogan (1945), and Vander Noot, Reese and Skelley (1947, 1948) found that the feeding of thiouracil to fattening swine resulted in faster and more efficient gains. McMillen *et al.* (1947) reported that the addition of 0.1 percent thiouracil to the ration of swine caused a decrease in the average daily gain, yet the gains were more efficient than the controls. No significant differences in carcass quality were obtained.

Roberts and Dawson (1935) found that the growth of immature rabbits was retarded by the use of Fowler's solution. Also, there was impairment of fertility, and sexual activity with mature males, and with breeding females a greater number of services were necessary for conception. However, the feeding of Fowler's solution to either the dam or sire had no effect on the growth of the progeny. Bull, Olson and Kammlade (1931), and McCulloch and St. John (1940) postulate that Fowler's solution or arsenic compounds may be the cause of "black cutters."

Yonkman (1929) found that strychnine injected in dogs increased both the frequency and amplitude of large peristaltic contractions in the small intestine and also increased the rhythmic contraction and tone of the intestine. Gruber *et al.* (1932) produced similar results though more varied and not as conclusive.

Materials and Methods

During the first year, 1946, twenty-four two-year Hereford heifers grading good as feeders were divided equally according to weight, type, and condition into four uniform lots of 6 heifers each. The second year, 1947, forty yearling Hereford heifers grading medium to good were similarly divided into four lots of 10 head each. The cattle used in each year's trial were purchased from the same breeder and were therefore of similar breeding.

The heifers were hand fed until they were on a full-feed of grain, at which time the cattle were self-fed in order to eliminate any favoritism which might arise from hand feeding. After the cattle had been on self-feeders a

short period, the drugs were added to the grain mixture and the experimental study was initiated. The heifers were individually weighed on three consecutive days at the beginning and again at the close of the trials and at two week intervals during the experiment.

In 1946, the drugs were added to the grain mixture during a 120-day feeding period (June 14 to Oct. 12), following which there was a depletion period (drugs removed from the ration) of 41 days prior to slaughter. In the second year, the drugs were fed for a 201-day period (March 22 to Oct. 9) followed by a variable depletion period prior[3] to slaughter.

The basal grain ration used was the same for each year, consisting of the following: 64 parts ground barley, 12.5 parts ground oats, 12.5 parts dried molasses beet pulp, 6 parts ground cull peas, and 5 parts wheat bran by weight. In the first year, a mixed grass-alfalfa hay was fed free choice and in addition a small amount of wheat pasture was available during the early part of the summer. In the second year's trial the heifers were fed in dry-lot and the roughage consisted of alfalfa hay, free choice.

TABLE 1. RATIONS AND DRUGS FED TO CATTLE[1]

Lot number	Number of animals[2] (1946)	Number of animals (1947)	Rations fed
I	6	10	Basal ration
II	5	10	Basal ration plus 18 grams arsenic trioxide (As_2O_3) per 1000 lbs. feed
III	5	10	Basal ration plus 300 grams nux vomica per 1000 lbs. feed
IV	6	10	Basal ration plus 2 lbs. thiouracil per 1000 lbs. feed (0.2 per cent of grain ration)

[1] The rate of feeding drugs represented the joint recommendation of Dr. J. E. McCoy, Dr. E. C. McCulloch and Dr. P. A. Klavano all of the College of Veterinary Medicine, State College of Washington.

[2] One death loss occurred in each of lots II and III with cause not diagnosed.

Arsenic trioxide was used instead of Fowler's solution for the reason that a dehydrated form of the drug was desired, and the arsenic itself is the active ingredient of Fowler's solution. The drugs were mixed with the grain ration in quantities of 1000 pounds of grain mixture. The respective drugs were first carefully and thoroughly mixed with 50 pounds of wheat bran using a small cement mixer which had been fitted with a dust tight cover. The 50 pounds of bran containing the drug were then mixed with

[3] No depletion period on 2 heifers in each lot; 3 heifers in each lot were depleted 36 days prior to slaughter; the remaining 5 heifers in each lot were depleted for 40 days.

the remainder of the 1000 pounds of grain mixture using a large feed mixer.

Each year at the close of the drug feeding period, hair samples one centimeter square in size[4] were taken from the right side of each animal at the point midway between the hip bone (tuber coxae) and the point of the shoulder (lateral tuberosity of the humerus). Determinations of number, length, and density of individual hairs were made from these samples. Also the luster of the hair coat was noted.

In 1947 only, the breeding efficiency and fertility was studied through exposing the heifers in each lot to each of two bulls (5 heifers to each bull). The breeding program was initiated 149 days after the start of the drug feeding period and continued until the close of the trials.

Each year at the time of slaughtering, post mortem studies were made in order to determine any possible pathological or physiological effects of the drugs upon the internal organs, reproductive tract, and glands (including the thyroid gland.)

A study was also made on the dressing percent, carcass grade, and thickness of fat over the eye muscle at the twelfth rib. The state of pregnancy was noted in the 1947 trials.

Results and Discussion

Feed Consumption and Feed Efficiency

Results of the management and production phases of this study are summarized and found in table 2 and figure 1. The animals receiving nux vomica and thiouracil made gains at lower costs than were obtained in the control lot. In 1946, the cattle in the thiouracil and nux vomica lots required 13.99 and 4.67 percent less feed respectively than the control animals. In the second year's work the addition of these drugs resulted in 6.14 and 2.98 percent decreases in the amount of feed required per hundred pounds gain. The lot of cattle fed arsenic trioxide and the control lot consumed approximately the same amount of feed each year, and therefore the costs of the gains were practically the same. Addition of thiouracil to the grain ration decreased its palatability and consequently the cattle consumed less grain and more hay. This is in agreement with the work of Muhrer and Hogan (1945) in an experiment on swine and also with Beeson *et al.* (1947) and Andrews *et al.* (1947) in experiments on cattle and sheep. The decrease in feed consumption and lowered feed costs in the thiouracil fed lot of heifers may be due to a lower metabolic rate inasmuch as MacKenzie and MacKenzie (1943) and Astwood (1943) noted a drop of 10 to 30 percent in the B.M.R. of rats fed goitrogenic compounds.

[4] Samples were taken by means of the Hardy Density Clipper, and kindly loaned by C. G. Potts, Bureau of Animal Ind., U.S.D.A., Beltsville, Md.

TABLE 2. EFFECT OF DRUGS ON GROWTH, FEED CONSUMPTION AND FEED EFFICIENCY OF HEIFERS, 1946 AND 1947

Item	Lot number and drug fed 1946 trials, 120 day drug feeding period				Lot number and drug fed 1947 trials, 201 day drug feeding period			
	I Control	II Arsenic trioxide	III Nux vomica	IV Thiouracil[2]	I Control	II Arsenic trioxide	III Nux vomica	IV Thiouracil
No. of heifers per lot	6	5	5	6	10	10	10	10
Growth Rate								
Av. initial wt., lbs.	802.3	821.2	802.8	803.6	496.0	497.9	497.4	496.4
Av. final wt., lbs.	1,071.2	1,109.2	1,098.4	1,116.5	935.8	946.2	964.5	911.9
Daily gain per heifer, lbs.	2.24	2.40	2.46	2.60	2.19	2.23	2.32	2.07
Daily Feed Consumption per Heifer								
Grain, lbs.	20.97	22.16	20.12	17.89	17.16	17.46	17.84	14.24
Hay, lbs.	3.14	3.63	5.17	6.22	4.89	4.77	4.88	6.04
Total, lbs.	24.11	25.79	25.29	24.11	22.05	22.23	22.72	20.28
Feed Required per Hundred Pounds of Gain								
Grain, lbs.	935.7	923.3	816.8	686.1	784.4	782.9	767.5	688.7
Hay, lbs.	140.0	151.4	210.3	239.3	223.7	213.9	209.9	292.3
Salt, lbs.	1.67	0.52	0.98	1.28	1.99	2.52	2.52	2.71
Bonemeal, lbs.	2.12	1.04	0.91	1.69	0.45	0.56	0.43	0.48
Total, lbs.	1,079.49	1,076.26	1,028.99	928.37	1,010.54	999.88	980.35	948.19
Feed Cost[1]								
Per 100 lbs. gain	$22.56	$22.42	$20.88	$18.38	$29.33	$29.17	$28.61	$26.77

[1] Figured at the prevailing feed prices in 1946 and 1947.

[2] Thiouracil kindly furnished gratis by Lederle Laboratories, Pearl River, New York, through the courtesy of Dr. T. H. Jukes.

Although the data on efficiency of feed utilization were not adapted for statistical analysis, it is highly probable that the large differences existing between the control and thiouracil lots are significant. The efficiency of feed utilization of the heifers fed thiouracil was much greater than that reported by Beeson *et al.* (1947).

The intake of thiouracil, however, was several times larger than the amounts fed by these workers (1947), which can concievably account for the greater efficiency of feed utilization. Likewise the sex of the animals used may be a factor. Mixner, Reineke and Turner (1944) showed that female White Rock chicks exhibited a greater response than did male chicks when fed 0.1 percent thiouracil in the ration.

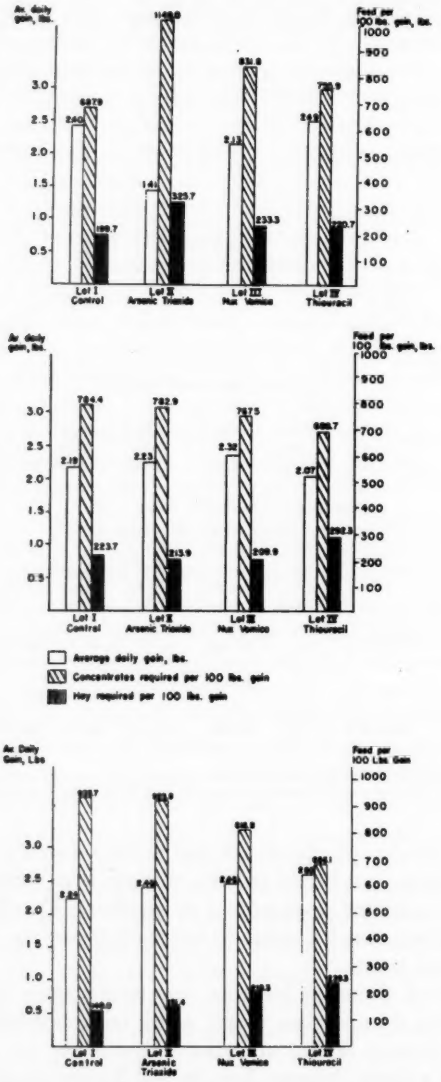

Lot I Control
Lot II Arsenic Trioxide
Lot III Nux Vomica
Lot IV Thiouracil
Average daily gain, lbs.
Concentrates required per 100 lbs. gain
Hay required per 100 lbs. gain

Figure 1. Average daily gains of heifers and feed required per hundred pounds gain. Top, 27-day drug depletion period 1947 trial; Center, 201-day drug feed period 1947; Bottom, 120-day drug feeding period 1946.

In the 1946 trials there was no significant difference between the gains of the animals of the drug lots and the controls. However, in the second year's work the rate of gain of the heifers fed arsenic trioxide and nux vomica was significantly increased ($P=0.05$) while the addition of thiouracil decreased the rate of gain.

TABLE 3. SUMMARY OF ANALYSIS OF VARIANCE OF RATE OF GAIN—1947

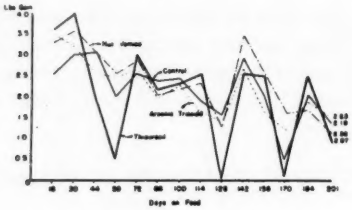
Source of variation	Degrees of freedom	Mean square	F Value
Total	39	1,814.89	
Lot	3	4,583.09	2.89*
Error	36	1,584.20	

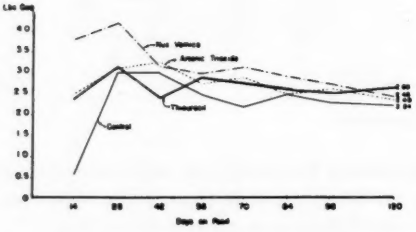
* Significant at the 5 percent level.

The heifers fed during the second year were somewhat younger and were fed for a longer period of time than those in the 1946 trials, which may in part account for this difference in response to the drug.

Since some feeders assume that the addition of drugs to the grain ration has a greater effect upon the rate of gain over a short feeding period than an extended one, the two-week interval weighing periods were analyzed from this standpoint. These data are summarized in figure 2. As shown, the average daily gains in all lots of heifers tended to level off at the end of the 120 and 201 day feeding periods. This, is more evident in the first year's trials. All the drugs were more effective in increasing the average daily gains during the first month of the drug feeding trials. Schweigert *et al.* (1948) concluded that environmental temperature was a factor influencing the rate of gain of animals fed thiouracil. However, statistical correlation made between the average daily gains at two week intervals and the averge daily mean temperature for the same periods in the 1947 trials failed to show any relationship between gains and temperature under the conditions of this trial ($n=14$, $r=-0.48$). The temperature varied during this period from 47.5°F. to 70.0°F.

Several stockmen have expressed the opinion that drug fed cattle will "go to pieces" when the drug is suddenly removed from the ration. In the 1947 trials, opportunity for the study of the behavior of all lots of animals during a 27 day drug depletion period. During this time the animals received the same handling and the same ration as fed previously, with the exception that no drugs were added to the grain mixture. During this period the rate of gain of the cattle which had previously received arsenic trioxide dropped very sharply from 2.24 to 1.41 pounds per day. At the same time the amount





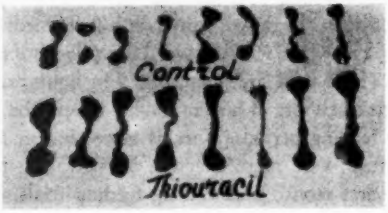


Figure 2. Average daily gains of heifers as indicated by weights taken at two week intervals. (Top 1947 trials, Bottom 1946 trials.) Figure 3 Top shows thyroid glands of the control and thiouracil lots of cattle, 1947 trials. Note increased size of glands from cattle fed thiouracil. Bottom picture shows representative lot of cattle used in 1946 trials. Note type of self-feeder in background.

of feed/100 lbs. gain for the animals in both lots II (arsenic trioxide) and lot III (nux vomica) increased respectively from 1010.54 and 999.88 to 1480.27 and 1069.45. The heifers in lot IV (thiouracil) however continued almost in the same manner as when the drug was included in the ration. This sudden decrease in the rate of gain of the heifers in lot II (arsenic trioxide) substantiates the belief of many cattlemen regarding the removal of Fowler's solution from the ration of fattening cattle. It is interesting to note that during this 27 day drug depletion period the heifers in lot IV (thiouracil) consumed grain and hay in almost the same proportion as the control lot, no longer being low on grain consumption and high on forage consumption. This change in grain consumption is probably accounted for by the fact that thiouracil is not palatable for cattle.

TABLE 4. EFFECT OF FEEDING DRUGS ON THE REPRODUCTIVE ORGANS OF HEIFERS 1947

Item	Lot no. and drug fed			
	I None	II Arsenic trioxide	III Nux vomica	IV Thiouracil
Number of heifers in each lot	10	10	10	10
Number of normal pregnancies at time of slaughtering	9	6	9	10
Number of normal reproductive organs but not pregnant	1	2	1	—
Number of abnormal reproductive organs found	—	2[1]	—	—
Number of services per lot	11	11	13	13
Number of services per conception	1.22	1.83	1.44	1.30

[1] Infantile organs both diagnosed as free-martins.

Reproduction and Carcass Studies

Although it was impossible to carry the heifers through the complete gestation period, some results on breeding efficiency were obtained in the 1947 feeding trials. The data obtained are summarized in table 4. At the time of slaughter, two heifers in the arsenic trioxide lot were found to have abnormal reproductive tracts. These were both diagnosed as free-martins. These free-martins were never observed to be in estrum and did not accept the bull, therefore they had no influence on the number of services per con-

ception in this lot. In both the control lot of heifers and the group fed nux vomica, 90 percent conception resulted with 1.22 and 1.44 services per conception respectively, and in the thiouracil lot, 100 percent conception was obtained with 1.30 services. In the arsenic trioxide lot, omitting the two free-martins, 75 percent conception resulted from 1.83 services per conception. The data on breeding efficiency were analyzed according to Snedecor (1946, section 9.10), the assumption being made that the probability of conception is independent of the number of services, that is, the probability of conception is the same regardless of whether it is the first, second, or third service ($X^2 = 2.30$, $df = 3$, $P = 0.51$).

TABLE 5. SUMMARY OF ANALYSIS OF VARIANCE OF DRESSING PERCENTAGE, 1947

Source of variation	Degrees of freedom	Mean square	F Value
Total	39	2.70	
Lot	3	8.87	4.01*
Error	36	2.21	

* Significant at the 5 percent level.

Although greater numbers of animals should be studied, the results obtained in this experiment would indicate that the rate of conception of the heifers was not affected by the feeding of any of the drugs at the levels used in this study. Dawson and Roberts (1935) found that the feeding of Fowler's solution to rabbits resulted in a greater number of services per conception and also the fertility of some of the treated animals was permanently impaired.

In 1946, the differences in dressing percentages were not significant, however in the second year's work the differences were slightly significant.

The cattle in both the arsenic trioxide and nux vomica lots dressed higher than the cattle in the control lot. The heifers fed thiouracil dressed about the same as the untreated lot of heifers in both trials. In 1946, with a shorter feeding period of 120 days the carcass quality, as measured by government grading standards, was considerably improved by the addition of drugs to the grain ration of the heifers, table 6. Beeson *et al.* (1947) reported a slight, though distinct, tendency for cattle fed thiouracil to be fatter. Andrews *et al.* (1947) found marked improvement of carcass quality of lambs fed 0.175 and 0.33 grams of thiouracil daily. In the 1947 trials, after the longer feeding period of 201 days, the carcass quality was not affected by the addition of the drugs. The thickness of fat over the twelfth rib was not affected as measured statistically in either 1946 or 1947 trials.

At the end of the first year's trials it was impossible, due to slaughtering technique to save any whole intact thyroid glands of the cattle. However, small pieces were saved for histological studies. There appeared to be less colloid in the glands of the thiouracil fed heifers. No marked pathological

TABLE 6. EFFECT OF FEEDING DRUGS ON DRESSING PERCENT, THICKNESS OF FAT OVER RIB EYE, CARCASS GRADE, AND THYROID WEIGHT ON HEIFERS 1946 AND 1947

Lot No. & Drug Fed	I None	II Arsenic trioxide	III Nux Vomica	IV Thiouracil
1946 Trials (120 days)				
Average dressing percentage	61.54	63.47	63.11	61.72
Thickness of fat over rib eye at 12th rib, inches	0.55	0.70	0.55	0.61
Carcass grades				
AA (Choice)	3	3	4	6
A	3	2	1	0
1947 Trials (201 days)				
Average dressing percentage	61.96	62.80	63.21	61.08
Thickness of fat over rib eye at 12th rib, inches	0.74	0.90	0.80	0.77
Carcass Grades				
AA (Prime and Choice)	10	9	10	9
A	0	1	0	1
Average thyroid weight, grams	17.09[1]			35.39[2]

[1] Average weight of 8 glands.
[2] Average weight of 9 glands.

effects were noted in other organs at the time of slaughter. In 1947, the thyroid glands of the heifers receiving thiouracil were 2.3 times larger than the glands of the control group of animals (figure 2). Similar results in thyroid enlargement were noted by Andrews *et al.* (1947), Andrews and Schnetzler (1946) and Beeson *et al.* (1947).

It should be pointed out that the average weight of the thyroid gland of the untreated yearling heifers, in the 1947 trials, were 17.09 grams (table 8) whereas Beeson, Andrews and Brown (1947) reported an average thyroid weight of 69.7 grams in their untreated yearling steers. The experimental steers used by the Purdue workers were fed from November 28, 1945 to

May 1, 1946, while the heifers studied in this trial were on experiment from March 22, 1947 to October 9, 1947. This seasonal difference may account for the variation in thyroid weights. Ring (1939), Schultze and Turner (1945) state that low temperatures stimulate the thyroid to increased activity and results in increased metabolic rate. Sex and weight may also be factors in influencing the weight of the thyroid gland in cattle. The steers used by Beeson, Andrews and Brown (1947) averaged 224 pounds heavier than the heifers, used in this trial, at the time they were slaughtered. Schultze and Turner (1945) showed that in white leghorn chickens of the same age the thyroid glands of male birds were 65.1 mgs. heavier than the glands of the female chickens. The average body weight of the male chickens was 1450 grams compared to an average weight of 1170 grams for the female chicks.

The analyses of hair samples one centimeter square for number of hairs, average length, and density failed to show any statistical differences due to the addition of the various drugs. No differences were noted in the luster of the hair coats of the different lots of heifers.

The effect of the feeding of these drugs on blood chemistry and blood counts, as well as the arsenic and strychnine content of the lean tissue and internal organs will be reported later.

As a further check on the chemical analyses, and to make certain that sufficient quantities of the arsenic, strychnine and thiouracil did not remain in the tissue at the time of slaughter to be injurious, 21-day old rats were fed composite samples each of lean tissue and internal organs at 30 and 80 percent levels in their ration. No detrimental effect on growth or hair coat was noted. These biological studies showed that even at high levels of consumption of both lean meat and internal organs there was no carry over of the drugs in the meat in sufficient quantity to have any effect on the growth performance of rats. Thus, it might be assumed that the carcasses were probably safe for human consumption. This might be expected with the heifers fed thiouracil, since Franklin, Boehne and Jukes (1948) showed that thiouracil disappears within a few days after its removal from the ration.

Summary

Feeding arsenic trioxide, nux vomica or thiouracil under the conditions of this experiment, resulted in a higher efficiency of feed utilization, and a lowered feeding cost. The best results were obtained by the addition of thiouracil when fed at a level of 0.2 percent, to the grain ration. The inclusion of the thiouracil in the grain mixture caused a decrease in grain consumption and an increase in the roughage consumption. The decrease in grain consumption was probably due to thiouracil reducing the palatability of

grain mixture. During a 27-day thiouracil depletion period, the proportion of grain and roughage consumption became almost identical to that of the control lot of heifers. The rate and efficiency of gain of the arsenic trioxide lot of heifers declined very sharply during the same depletion period, while the nux vomica lot of heifers continued with satisfactory gains. The efficiency of feed utilization, however, was greatly lowered. The appetites of all the animals in each lot remained very good.

All three drugs increased the rate of gain most markedly during the first month of the feeding trials.

Addition of any of the drugs to the grain ration did not affect the hair coast as measured by length, weight, density and luster.

Daily temperature, prevelant in these trials, had no effect upon the rate of gain of the cattle receiving thiouracil.

The thyroid glands of the yearling heifers, fed thiouracil for 201 days, were 2.3 times larger than the thyroids of the control heifers. No marked pathology was noted; however, there tended to be a decrease in colloid content of the glands of the heifers fed thiouracil.

Although a larger number of animals should be studied, there was no evidence that any of the drugs at the levels fed had any effect on rate of conception or reproduction.

The difference in dressing percentages of the various lots was not statistically significant. The drugs had no effect on carcass quality or grade of yearling heifers during a long feeding period. However, during a short feeding period, the carcass grade of two-year-old heifers appeared to be slightly increased by the addition of thiouracil to the ration.

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OBSERVATIONS ON EFFICACY OF VITAMIN SUPPLEMENTS FOR NEW-BORN CALVES[1]

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Lundquist and Phillips (1942, 1943) and Phillips and Lundquist (1941, 1944) have reported supplementary vitamins to be effective in reducing the incidence of diarrhea and death loss in calves. These results could not be confirmed by Hibbs and Krauss (1947), Nevens, *et al.* (1947) and Norton, *et al.* (1946) using Experiment Station calves. Spielman, *et al.* (1948) could observe no beneficial effects from feeding supplemental vitamins to calves raised under varying farm conditions. Eaton, *et al.* (1947) observed that feeding massive doses of vitamins A and D on the day of birth was as effective for maintaining blood plasma vitamin A levels to forty-two days of age as was daily doses or doses at three and ten days of age.

The purpose of this experiment was to determine whether or not massive doses of vitamins A and D administered on the day of birth resulted in a beneficial response in dairy calves under varying farm conditions.

Procedure

Forty-eight dairymen located in the irrigated and coastal sections of Washington, two dairymen in Rhode Island and nine dairymen in New Hampshire cooperated on this experiment. Each cooperator in Washington and Rhode Island was personally contacted, and the condition of calves and housing rated. Since previous experimental work had indicated that the greatest trouble from scouring occurred in the winter and spring months, this trial was conducted from November, 1947 to April, 1948 in Washington and Rhode Island and from January to June, 1947 in New Hampshire.

Two types of colored pellets were supplied to each cooperating dairyman in accordance with his estimated needs. The brown pellets contained 125,000 International Units of vitamin A, 25,000 International Units of vitamin D and 250 milligrams of niacin. The white pellets contained inert material. Cooperating dairymen did not know which color pellet contained the vitamins. Directions for administration of the pellets, together with buff

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and white cards for reporting results were mailed with the pellets. Dairymen were instructed to give each calf born either two of the brown or two of the white pellets on the day of birth and to alternate the color of pellet given to each succeeding calf born. Records of incidences of scours, colds, pneumonia and other abnormalities were kept on each calf for eight weeks on the Washington calves, after which the cards were mailed in for analysis. Records were available for the first thirty days on the Rhode Island and New Hampshire calves.

In February, 1948, blood samples were collected from 68 of the Washington calves for vitamin A and carotene determinations, using the methods of Kimble (1939). Also, four composite blood samples, two each from control and experimental calves, were collected and assayed for vitamin D. Each sample was composited from four calves.

Results and Discussion

Results were reported on 265 calves in Washington, 44 calves in Rhode Island, and 38 calves in New Hampshire.

As shown in table 1, 61.2 percent of the Washington calves receiving

TABLE 1. SUMMARY OF WASHINGTON EXPERIMENTAL DATA

Calves	Holstein	Jersey	Guernsey	Mixed	Total
Experimental					
Number	69	31	31	9	139
Percent that showed normal health	73.9	61.3	33.3	55.6	61.1
Percent that had scours, pneumonia, etc.	21.7	29.0	60.0	44.4	33.1
Percent that died	4.4	9.7	6.7	0	5.8
Controls					
Number	64	28	26	8	126
Percent that showed normal health	81.3	60.7	53.8	50.0	69.0
Percent that had scours, pneumonia, etc.	15.6	35.7	38.5	25.0	25.4
Percent that died	3.1	3.6	7.7	25.0	5.6

vitamin supplementation did not have colds, pneumonia or scours during the eight weeks experimental period; 33.1 percent had scours, colds or pneumonia and 5.8 percent died. The control calves showed less disorders in that 69 percent were untroubled, 23.4 percent had scours, colds or pneumonia and 5.6 percent died.

Two Holstein herds (one well managed and one poorly managed) in Rhode Island reported 20 percent scours for the control calves and 16.7 percent for the experimental calves (table 2). The well managed herd reported only one slight case of scours.

TABLE 2. SUMMARY OF RHODE ISLAND AND NEW HAMPSHIRE EXPERIMENTAL DATA

Location	No. of calves	Incidence of		Condition at 30 days of age		
		Scours percent	Death No.	Good percent	Fair percent	Poor percent
Experimental						
Rhode Island	24	16.7	2	91.7	8.3	0
New Hampshire	17	41.2	0	94.1	0	5.9
Controls						
Rhode Island	20	20.0	0	90.0	5.0	5.0
New Hampshire	21	52.4	0	100.0	0	0

Nine herds in New Hampshire reported 52.4 percent scours for the control calves and 41.2 percent scours for the experimental calves. These calves were predominantly Jerseys and Guernseys. Growth rate comparisons for the first thirty days were available on a limited number of calves in this study. No difference in rate of gain was observed.

When the above data were combined, 31.7 percent of 180 experimental calves scoured, whereas 32.3 percent of 167 control calves scoured.

Thirty of the forty-eight cooperating dairymen in Washington were surveyed in June and July, 1947. Detailed notes were made on methods of feeding and managing calves and complete descriptions were made of housing conditions. In addition, the condition of calves and the adequacy of housing were rated. Since this inspection was made in June and July, it was felt that the condition of calves was more reflective on feeding and management than on conditions of housing. The authors are well aware of the variations that could appear by applying these ratings to vitamin supplementation studies conducted on these same farms six to eight months later. Though no changes in method of housing were made, it is possible that some changes were

made in methods of feeding and management. Data were accordingly segregated on the basis of these previous ratings on the condition of calves, on conditions of housing, and on the combined evaluation of both criteria. These data as shown in tables 1, 2, 3 and 4 reveal that lower incidence of diarrhea was reported for the controls under all conditions studied. This serves to indicate, superficially at least, that massive supplementation of vitamins A and D on the day of birth should not be expected to compensate for inadequate care and housing.

TABLE 3. COMPARISON OF THE RATINGS OF APPEARANCE OF CALVES IN JUNE AND JULY, 1947 TO REPORTS RECEIVED ON FEEDING PELLETS DURING THE WINTER AND SPRING OF 1947–48

Rating of calves[1]	Control calves		Experimental calves		All calves	
	Total number	Percent scouring	Total number	Percent scouring	Total number	Percent scouring
Very good	47	10.6	48	20.8	95	15.8
Good	26	42.3	32	46.9	58	44.8
Fair	19	47.4	21	61.9	40	55.0
Poor	7	57.1	6	66.7	13	61.5
Total	99	29.3	107	39.3	206	34.5

[1] Description of ratings:

Excellent—thrifty appearing, no sign of disorders and sleek hair coats. No calves on farms later cooperating received this rating.

Very good—thrifty appearing, no sign of disorders and dry appearing hair coats.

Good—moderately thrifty, slight indication of disorders and rough dry hair coats.

Fair—unthrifty, indication of disorders and rough dry hair coats.

Poor—definitely undersize, indications of scours and colds and very rough hair coats.

Blood samples were drawn from 32 Holstein calves which received the vitamin supplementation and assayed for vitamin A and carotene. The average age of these calves was 46 days at the time of bleeding. The average blood plasma carotene value was found to be 48.06 micrograms per 100 ml. of blood plasma, while the average vitamin A value was 11.06 micrograms per 100 ml. of blood plasma.

Blood samples from 36 Holstein calves which received the placebos were also assayed for carotene and vitamin A. At the time of bleeding, the average age of these calves was 48 days. The mean blood plasma carotene level was 44.56 micrograms per 100 ml. and the mean vitamin A level was 9.78 micrograms per 100 ml.

According to Boyer *et al.* (1942) venous blood plasma vitamin A levels of ten micrograms per 100 ml. or more are necessary to maintain adequate vitamin A nutrition in the growing calf. Levels of seven to nine micrograms per 100 ml. of blood plasma are borderline and values below seven

TABLE 4. COMPARISON OF THE ADEQUACY OF CALF HOUSING TO THE INCIDENCE OF SCOURING REPORTED

Rating of barns[1]	Control calves		Experimental calves		All calves	
	Total number	Percent scouring	Total number	Percent scouring	Total number	Percent scouring
Excellent	32	3.1	36	8.3	68	5.9
Very good	14	28.6	14	57.1	28	42.9
Good	22	50.0	25	52.0	47	51.1
Fair	20	25.0	20	40.0	40	32.5
Poor	11	72.7	12	83.3	23	78.3
Total	99	29.3	107	39.3	206	34.5

[1] Description of ratings:

Excellent—well lighted, well ventilated and free from drafts, easily kept dry and clear and free from odors.

Very good—well lighted, well ventilated, and free from drafts, not easy to keep clean and dry but relatively free from odors.

Good—poor lighting, fairly well ventilated, slightly drafty, difficult to keep clean and dry with calf ordors noticeable.

Fair—poor lighting, poor ventilation, windows present, moderately drafty, difficult to keep clean and dry with calf odors markedly noticeable.

Poor—dark interior, no windows, drafty and foul odors, or no structure available for housing calves.

are definitely inadequate. The blood plasma vitamin A levels of the 32 Holstein calves receiving the vitamin supplementation and the 36 Holstein calves receiving placebos were grouped according to the ranges suggested by Boyer *et al.* as being adequate, borderline, or deficient, respectively. Of the calves which were supplementally fed, 69 percent had adequate plasma vitamin A levels, 22 percent were borderline, and 9 percent were deficient. Of the calves given placebos, 42 percent showed adequate blood plasma vitamin A levels, 33 percent were borderline, and 25 percent were deficient.

Four composite blood samples, two from calves receiving brown pellets and two from calves receiving white pellets, were collected and assayed for vitamin D. These results, as shown in table 6, indicate that the blood plasma of calves receiving supplemental vitamins had approximately 2.5 times more vitamin D than the plasma of calves fed placebos.

TABLE 5. COMBINED RATINGS ON CONDITION OF CALVES AND ADEQUACY OF HOUSING ON PERCENTAGE OF CALVES SCOURING

Combined rating	No. of calves.	Percent scouring
Very good plus and very good	67	7.4
Good plus and good	86	39.5
Good minus and fair	35	54.2
Fair minus and poor	18	72.2
Total	206	34.5

TABLE 6. BLOOD PLASMA VITAMIN D LEVELS OF SUPPLEMENTED CALVES AS COMPARED WITH THE NON-SUPPLEMENTED CALVES

Sample No.	Average age of calves in days	Amount of vitamin D supplement	I.U. of vitamin D[1] per ml. blood plasma
1	27	None	0.56
2	27	None	0.38
3	28	50,000 I.U.	1.10
4	25	50,000 I.U.	1.18

[1] Assays in cooperation with Standard Brands, Incorporated.

Discussion

The incidence of scours, colds, and pneumonia in calves was not reduced in this investigation by oral administration of 250,000 I. U. of vitamin A, 50,000 I. U. of vitamin D, and 500 mg. of niacin on the day of birth. In fact, in the Washington experiment, 33.1 percent of the calves receiving vitamin supplements were troubled with scours, colds, or pneumonia as compared to 25.4 percent of the controls. The Rhode Island and New Hampshire data revealed slightly less scouring in the supplemented calves as compared to the controls. However, when the data from the three states were combined, 31.7 percent of 180 supplemented calves scoured as compared to 32.3 percent of 167 control calves. This confirms the work of Hibbs and Krauss (1947), Johnson *et al.* (1947), Nevens and Kendall (1947), Norton *et al.* (1946), Spielman *et al.* (1948) and Thorp (1943), indicating vitamin supplementation will not prevent early calfhood disturbances unless the calves are deficient in these vitamins.

Blood plasma vitamin A levels of calves approximately six weeks of age were increased from 9.78 micrograms per 100 ml. of blood plasma for the controls to 11.06 micrograms per 100 ml. of blood plasma for those calves which received vitamin A supplementation. The work of Eaton *et al.* (1947), Hibbs and Krauss (1947), Phillips *et al.* (1941) and Sutton and Kaeser (1946) is in agreement with these findings.

Blood plasma vitamin D values were approximately 2.5 times as high in those calves which received the vitamin D supplement as in the controls. Eaton *et al.* (1947) found liver storage of vitamin D to be ten times as high in the supplemented calves as in the controls.

Methods of feeding and management and adequacy of housing for calves were directly related to the incidence of scouring in this experiment. Those dairymen using the most acceptable methods of raising calves reported only 7.4 percent diarrhea in 67 calves during the experimental period, whereas

those doing the poorest job reported 72.2 percent diarrhea in 18 calves. These observations are in agreement with those of Spielman *et al.* (1948).

Blood analyses for carotene and vitamin A on 68 Holstein calves showed that 68.75 percent of the experimental calves had adequate blood plasma levels of vitamin A, whereas only 41.67 percent of the controls showed adequate levels at 46 and 47 days of age, respectively. Likewise, assays of four composite blood samples for vitamin D indicated the experimental calves were approximately 2.5 times higher than the controls. This is in agreement with Eaton *et al.* (1947), Sutton and Kaeser (1946), and Hibbs and Krauss (1947).

Summary

1. Two brown pellets containing 250,000 I. U. of vitamin A, 50,000 I. U. of vitamin D, and 500 mg. of niacin and white placebo pellets were alternately fed on the day of birth to 347 calves located on 48 dairy farms in Washington, two dairy farms in Rhode Island and nine dairy farms in New Hampshire. Records on scours, colds, pneumonia and death losses were recorded by cooperating dairymen for eight weeks in the Washington trial and for thirty days in the Rhode Island and New Hampshire trials.

2. There was no difference in the incidence of scouring; 31.7 percent of the calves supplemented on the day of birth scoured as compared to 32.3 percent for the controls.

3. The mean blood plasma vitamin A level of 32 experimental Holstein calves was 11.06 micrograms per 100 ml. of plasma as compared to 9.78 for 36 control Holstein calves at 46 and 47 days of age, respectively.

4. Only 9.38 percent of the 32 experimental Holstein calves had blood plasma vitamin A values below 7.00 micrograms per 100 ml. of plasma, whereas 25.0 percent of the 36 controls were in this range.

5. Blood plasma vitamin D values on four composite blood samples were approximately 2.5 times higher in experimental calves.

6. Supplementary feeding of a massive dose of vitamins to calves at birth was of no benefit in reducing colds, pneumonia, scours and death losses under a wide variety of conditions in Washington, Rhode Island and New Hampshire.

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SPECIAL METHODS FOR RUMEN BACTERIAL STUDIES IN THE FIELD[1]

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LITTLE work has been reported about the kinds and numbers of rumen bacteria found in cattle and sheep under practical farm conditions Therefore, a survey was undertaken to study rumen bacteria from animals fed various practical rations. Comparisons were made between species and within species on animals fed different rations, by means of direct slide counts, Gram stains and anaerobic culturing.

When this survey was undertaken, several technical difficulties were encountered, because this study was to be made under field conditions. The size of the animals made it impossible to bring them to the laboratory, and the situation was complicated further because rumen bacteria are obligate anaerobes, which must be cultured rapidly after sampling. This made it undesirable to transport the samples long distances before culturing. Therefore, it became necessary to set up a laboratory in the barn, where the maintenance of sterility, incubator temperature, and anaerobic conditions without proper facilities became a real problem.

The purpose of this paper is to describe the special devices and technics used to overcome these difficulties. The results of these studies, together with a discussion of their application to animal husbandry, will be presented in a following paper (Gall *et al.* 1949).

Experimental Technics

Sampling

Samples were obtained by stomach tube from the intact animal, using the following procedure. A large bore rumen tube ($\frac{3}{4}''$) or a regular, smooth garden hose were used for withdrawing the sample from cattle, while a medium bore rumen tube ($\frac{1}{2}''$) was employed for the sheep. A speculum was tied in the animal's mouth, and the tube inserted carefully to avoid the lungs and saliva contamination. The tube should be inserted once only and with as little irritation and drawing back and forth as possible. The tube should be blown out after insertion into the rumen before collecting the sample, and the saliva on the outside of the tube prevented from entering the flask while draining the tube.

The collection process itself was simple. After the tube had been inserted

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into the rumen, it was attached, by means of an adapter in a rubber stopper, to a suction flask. A hand pump was fastened to the side arm of the flask by a rubber tube, and about 200–500 ml. of the rumen contents were drawn out by suction. The contents were mostly liquid with some solid material. The solid portion was collected by squeezing the sample through cheese cloth which retained the large particles. The liquid portion was tested for pH by glass electrode within 15 minutes of collection time. Dry matter was determined on each sample by filtration and drying at 75° C. for 24 hours. Samples were usually taken in the latter half of the morning.

Culturing

Ten grams of the solid material were weighed out, and placed in a bottle in 90 ml. sterile distilled water, which had been stoppered immediately after autoclaving, with a rubber stopper. Carbon dioxide or nitrogen gas was bubbled through this 1:10 dilution for 1–2 minutes after which the bottle was stoppered and placed in the mechanical shaker for 3 minutes. Further dilutions of 10^{-3} and 10^{-5} were made in water blanks prepared as described above, which had been flushed out with carbon dioxide or nitrogen gas immediately before use. One c.c. of 10^{-5} was used to make the 10^{-6} dilution in 9 c.c. of rich organic broth+cotton, (Gall *et al.*, 1947) modified by omitting the milk, and to have a pH of 6.8. This was serially transferred as above to make cultural dilutions 10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}, 10^{-10} and 10^{-11}. All tubes were placed in a boiling water bath for 10 minutes and cooled just prior to inoculation. The tubes were sealed with vaspar immediately after inoculation, and incubated at 37.5°. These processes should be completed within 15–20 minutes after taking the sample.

After inoculation, incubation at 37.5° was carried out for 60 days, or until growth occurred. After growth the culture was studied by Gram stain, pH determination and inoculation into an agar shake. This last technic gave information about the aerobic or anaerobic character of the culture and permitted study of the isolated colony, usually a pure culture, which could be tested for its ability to split fiber, or any other physiological characteristic desired.

Gram stain

Gram stains were made from the 1:10 dilution of the rumen contents and were examined microscopically. The predominance of the various morphological types of organism was observed, and special note was made of the bacteria attached to the fiber.

Nigrosine counting slides

The principle used in this counting method is the same as that of the direct milk count (Wadsworth, 1939). However, certain modifications have been made to adapt this technic to our special purpose. The method in brief follows. A 0.01 ml. portion of the properly diluted sample is mixed with a 3 mm. loopful of saturated methyl alcohol solution of water-soluble nigrosine and spread evenly over a 2×2 cm. area of a very clean slide. This slide is dried quickly on a very hot electric plate, and 10–20 fields counted. The organisms appear white against a black background, while debris takes the darker color and will not be confused with the bacteria.

The first essential to this technic is an absolutely clean slide. New slides were soaked in alcohol for at least ½ hour, removed with forceps, and dried with quick long motions with an absolutely clean "non-linty" towel. The 2×2 cm. square was marked on with a wax pencil, and care was taken that no particles of wax pencil or dust remain in this area. The slides were stored in a partitioned covered staining jar, so that the slides do not touch.

The nigrosine was prepared as any saturated solution, filtered and placed in a tightly stoppered bottle. A large supply should preferably be made, so that it can be used over a long period, since minor adjustments in the amount of dye desired to give the proper black background must be made with each lot, to suit the individual.

The sample was diluted in distilled water so that there are about 10–40 organisms per field. This dilution usually is 1:1000. A 1:10 or 1:100 dilution was made first and shaken in a mechanical shaker for 3 minutes. Further dilutions were made from this and shaken by hand vigorously.

After shaking, 0.01 ml. of the sample was transferred by special Breed pipette to the center of the 4 cm. square, and the loop of nigrosine placed on the drop. Complete mixing was effected, using the loop to stir, and to spread the material in a thin film evenly over the slide. Usually it was best to end by rocking the slide from side to side to effect a very even color and to allow slight evaporation, so that there was not an excess of fluid when the slide is placed on the hot plate. The plate was very hot and the slide touched the plate at all points. Drying took 2–3 sec. at most and the slide was then removed from the hot plate.

Excess fluid often causes uneven drying. Too much or too concentrated dye causes cracking, while too slow drying causes a large area of shrinkage. An uneven plate causes ridges of dye, and any foreign particle causes an unstained area, which tends to be round.

The slide was counted only after a Gram stain of the original material had been examined. This acquaints the examiner with the types of organisms

which are present and during counting, any questionable-looking spots on the nigrosine slide were examined carefully unless they appeared to have the morphology of a bacterium seen on the Gram stain. For example, a perfectly spherical white spot would probably be an artifact, if no such perfectly round organism were seen on the Gram stain. A spherical area with cracks around it is usually caused by an air bubble.

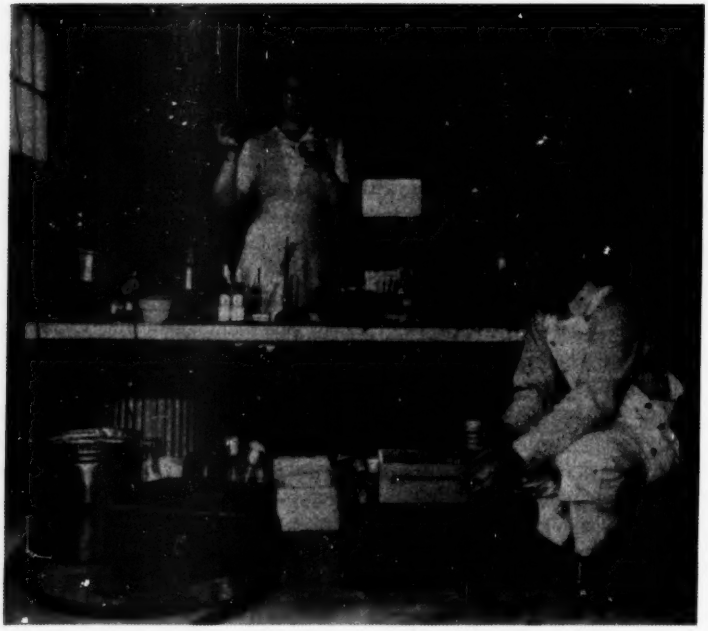

Figure 1. Field laboratory set-up for culturing rumen bacteria. Floor—foreground—incubator, rumen sampling equipment, shaker; background—boxes for transporting equipment with additional supplies; pail with gas cylinders and thermos jug. Table—sauce pans and hot plates, pan for cooling tubes, microscope, water blanks, pipette jar, slide jar, gas cylinder, alcohol lamp, pipette can, culture tubes, phenol bottle, interval timer, balance and collection flask. Background—left—pH meter on galvanized can.

Before counting, a survey of the slides was made to see that no part of the slide is unrepresentative. Then 10–20 fields from all parts of the slide were counted. There will be a narrow zone of shrinkage near the border. This will have a slightly lower count than the rest of the slide, but the inclusion of 1 field from this area in 10 fields will help to correct for this.

Chains or pairs are counted as one. Any field having much debris or a large light area was discarded.

The count per gram or ml. was calculated by multiplying the average of the fields with the factor obtained by calibrating the microscope with a certain set of oculars (usually ×10) using an oil immersion lens.

Special Methods and Equipment

Special methods and equipment were needed to carry out these procedures in a barn where the only facilities were electricity and a source of hot water. After several trials the following routine was established for setting up the "laboratory," and carrying out the studies.

The minimum personnel required were two trained laboratory workers, —one to do the bacteriology and the other to collect and prepare the sample for culturing, with a third person to assist with the animals, and help to collect the sample.

All equipment for culturing and collecting the sample was cleaned and sterilized in the "home" laboratory, and then packed in three boxes that could be placed in the truck or back seat of a passenger car. All breakable material was carefully placed in one box, which was tightly packed to prevent shifting. In addition to these three boxes a portable pH meter, mechanical shaker and microscope were taken along. A large lard pail with cover, three milk pails in which were placed small lecture-type cylinders of compressed gas, and a two gallon thermos jug completed the equipment.

Upon arrival at the barn, a small room or quiet corner near an electrical outlet was selected as the site of the "laboratory." A table at least 6′×4′ was necessary and an extra bench was helpful. Wrapping paper was spread over the table as a complete cover, and the materials for culturing and making slides were arranged conveniently on the table. As soon as possible, two sauce pans with lids, ¾ full of hot water, were placed on hot plates, turned to "high."

Extension cords were used so that the mechanical shaker could be placed on a rubber mat near the table, and the microscope and lamp set up on the table or on a bench. The pH meter was then set up on the bench and regulated, so that it was ready for use. A balance, accurate to 0.1 gm. was placed on one end of the table, and the evaporating dish used for weighing the sample was tared. Gas, from a small lecture tank, was bubbled through the water blanks which were restoppered immediately. The "incubator" used in the barn was a 50 lb. covered lard can containing water slightly above 37.5° C., in which a wire basket for holding the cultures was suspended. Additions of hot water at about ½ hour intervals kept the temperature nearly constant. Floating thermometers were used to check the temperature.

When the water in the sauce pans had come to a boil, the tubes for culturing the first animal were placed in one pan, with the lid only partly on, so that the cotton plugs stuck out. The other pan of water was held in reserve, to use for the tubes for the next animals so that even in cold weather boiling water was always available. The first sample was then taken as described above, and brought back to the "laboratory" for filtering, weighing, culturing and taking pH. The essential history of the animal and observations on the sample were recorded on printed sheets prepared for that purpose.

The sample was cultured anaerobically as described above, an alcohol lamp being used to flame the tubes and loops. After sealing the cultures, they were placed in the basket in the "incubator," and the lid replaced. Care must be taken not to wet the cotton plugs with water of condensation on the lid.

While the next animal was being sampled, the nigrosine counting slides were made, using the side of one of the hot plates for drying them. The slide was then checked under the microscope to see if the correct dilution had been used. The material for the Gram stain was placed on a slide and dried, but the staining was postponed until later.

The whole procedure for each animal should take only 20–25 minutes, and usually six animals were studied in one morning.

To maintain the cultures at or near 37.5° on the way to the laboratory, a two gallon thermos jug was used. The jug was filled with water at 50–60° C. to warm it. This water was emptied out and an ice cap full of 50° C. water was quickly placed in the jug with a layer of warm damp cotton over it. This helped to maintain the temperature. The warm cultures were packed in cellophane sacs, 6 to 10 in a group and placed in the jug, which was closed immediately. A laboratory thermometer could be inserted in the spigot at the bottom of the jug to check the temperature from time to time, so that more hot water could be placed in the ice cap if necessary. Upon returning to the "home" laboratory, the cultures were placed in a regular incubator.

Discussion

On the whole this method gave satisfactory results. It was possible to sample six animals in a morning without undue trouble, and the procedure was not too complicated to be readily duplicated. The sampling technic was especially important, since the study was primarily concerned with roughage digesting organisms. Ordinarily a sample drawn with the stomach tube is largely liquid, because the solid particles pass through the tube less easily and also because the sample frequently comes from the reticulum which is more liquid than rumen contents. The filtration of the contents to obtain the

solid portion overcame these difficulties. This sampling technic allowed the use of the intact animal, which offered great advantages in a survey of this kind.

It is recognized, however, that stomach tube samples are not ideal in two respects. Saliva contamination was experienced whenever a difficult collection was encountered. This affected the pH reading. Also, the exact place from which the sample was collected was not known for each sample. Many samples probably came from the reticulum rather than the rumen proper, but since studies of samples from various parts of the rumen and reticulum using a fistulated steer indicated little qualitative difference in bacterial flora of the solid material, it was felt that this was not too serious a handicap. Quantitative differences in bacteria found in various sections of the rumen and reticulum were largely overcome by the squeezing of the sample to obtain the solid portion which had about the same percent dry matter for each sample. The advantages of being able to sample the intact animal are obviously great.

Culturing under "field" conditions was not ideal. The chances for contamination were increased by the dust conditions in a barn. However, only two contaminations were found in the whole series, which was not considered significant. Also since each tube in the series represents a ten-fold dilution of the preceding tube, only large differences in numbers would be reflected in the cultural results. Much useful information was gained by these studies, and it is felt that with proper consideration of the limitations of the technics, the findings are of value.

Some environmental or nutritional factor appeared to be lacking in the broth used for culturing, as was shown in many cases by the failure of the bacteria (especially the ones associated with the fiber) to grow in as high dilutions as indicated by the slide count. The difficulty experienced in shaking the organisms off of the fibers also would contribute to the failure to culture these bacteria. Exposure to air during sampling or exclusion of carbon dioxide from the culture may both have contributed to this condition.

By observing the Gram stains, a quick comparison of the general morphological types present in the samples could be made. The appearance of a new morphological type or the disappearance of an organism usually present could be easily noted. It must be stressed that any comparisons made by means of the Gram stain are based on morphology only and the data should be interpreted with this limitation in mind.

Counts made from the nigrosine slides could be used to compare the numbers of bacteria present in the samples. The method is quick, the bacteria are easy to count, and debris does not interfere with the counting because it is dark colored while the bacteria are colorless. This method has its weakness,

however. In common with all slide counts, it is impossible to distinguish the living from the dead bacteria. Also, the counts obtained by this method were low. This was due to the fact that even after vigorous shaking, bacteria were still clinging to the fibers, so that the organisms which were free in the liquid after shaking were fewer than the total number present. The slide count was not intended to be extremely accurate, but was meant to give an indication of the numbers of bacteria present. It was felt, however, that since all samples were treated in the same way, the results would be of comparative value.

The methods, as devised, represent a compromise with the ideal, but much useful information may be obtained if the limitations of the technics are considered. When improvements are made in sampling and cultural methods, better information will be obtained.

Summary

1) Methods for studying the rumen bacteria of cattle and sheep under field conditions are described. The technics of sampling, culturing, and counting the bacteria in the rumen are described and discussed.

2) Special equipment and procedures needed to carry out these procedures under farm conditions are described.

3) The values and limitations of the technics employed are discussed.

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RUMEN BACTERIA IN CATTLE AND SHEEP ON PRACTICAL FARM RATIONS[1]

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THE kinds and numbers of bacteria in the rumen of cattle and sheep on practical farm rations is a question of considerable interest. Some workers, such as Baker (1943), have studied the kinds of bacteria microscopically, while others have cultured these bacteria. Hungate (1947) has succeeded in isolating cellulose-digesting bacteria from high dilutions of rumen contents. Van der Wath *et al.* (1948) have grown several rumen bacteria, one being an iodophilic coccus isolated from sheep and (Van der Wath, 1948) has also made direct counts of rumen microorganisms finding an average of 1–2 billion per ml. rumen contents. Köhler (1940) studied numbers of rumen bacteria by several technics. By direct count he found about 13 billion per gram, but by indirect means he calculated that there should be over 100 billion per gram. However, Köhler (1940) was able by aerobic culturing to grow only 25 million organisms per gram. Both Van der Wath (1948) and Köhler (1940) stated in their publications that their direct counts were too low, and Köhler (1940) also recognized that he was not culturing all of the important bacteria. Gall *et al.* (1947), using a direct slide count, found bacteria in numbers ranging from 50–100 billion per gram of fresh rumen contents, and by anaerobic cultural methods have frequently been able to culture the bacteria in the dilution indicated by the slide count.

This survey was undertaken in an effort to obtain information concerning the kinds and numbers of bacteria present in the rumen of cattle and sheep under practical farm conditions, both winter and summer.

Procedure

The methods used in this study have been described fully in a previous paper (Gall *et al.*, 1949). The animals studied included 21 cattle and 12 sheep on winter rations, and 11 cattle (6 beef and 5 dairy), and 6 sheep on pasture. The animals on winter rations were grouped in the following way. Six cattle and six sheep were fed fattening rations, four beef cows and six ewes were on breeding rations and the remaining 11 cattle were on dairy feed; five without and six with ensilage.

The pasture animals were tested in June after a month on lush pasture. Most of the animals sampled while on pasture had been previously studied during the winter.

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Results

Direct Slide Counts

The number of rumen bacteria as determined by slide counts on both cattle and sheep on winter rations showed averages of about 50 billion bacteria per gram of fresh rumen contents, with relatively little deviation, as is seen in table 1. An isolated instance of a high count (72.2 billion) occurred on one cow on winter rations. Both species gave higher slide counts when on pasture, the average being 96.1 billion for cattle and 85.4 billion for sheep. The slightly higher figure for cattle was due to the consistently higher count found in the five dairy cattle. In every case where the same animal was tested on both winter and summer rations, the count from the latter was the higher one.

Dry matter was run on each sample and the average for both cattle and sheep was about the same for each season, which should allow a fair comparison between the species.

The percentage of dry matter reported in table 1 was not the value for the rumen contents as collected by stomach tube, since these samples were largely liquid. As this study was especially concerned with rumen organisms capable of digesting roughage, an effort was made to simulate a solid sample by squeezing the stomach tube sample through cheese cloth. The percent of dry matter obtained by this method was not markedly different from that found in solid samples collected from the upper portion of the rumen of a fistulated steer.

In general, the bacterial slide counts for cattle and sheep on similar rations were about the same, but when the animals were on pasture they showed a higher count than when fed winter rations.

Gram Stains

Observations of Gram stains of rumen contents from both cattle and sheep on all winter rations failed to reveal any marked differences in bacteria between these species of ruminants fed different rations. A few more cocci were found on the high grain rations than on the low, but these differences were not great.

The morphology of the bacteria as revealed by Gram stains from cattle and sheep on pasture looked very much alike and also resembled the bacterial picture from animals on winter rations. However, many slides from pasture-fed animals showed a star-shaped cluster of organisms (see figure 2), similar to that drawn by Baker (1942), but never seen in this study on any winter rations. There were also many sarcina present in samples from the pasture-fed animals, while these organisms appeared during winter sampling

only in a few animals receiving ensilage. Neither of these two bacteria was a predominating organism.

From morphological observations of the bacteria present, therefore, it would appear that the bacteria seen in the rumen of both cattle and sheep on practical farm diets, winter and summer, are similar; but that a few more

TABLE 1. RESULTS OF RUMEN BACTERIAL STUDIES ON CATTLE AND SHEEP FED PRACTICAL RATIONS

Factors studied	Cattle				Sheep			
	Winter		Summer		Winter		Summer	
Average Bacterial count (Billions/gram)	52.2±6.9		96.1±18.2		51.2±6.5		85.4±4.2	
Average % dry matter of rumen sample	20.3±2.9		16.7± 1.9		20.1±2.3		15.5±2.3	
pH range of rumen sample								
Fattening ration	6.3–6.7				6.4–6.9			
Breeding ration	7.0–7.3				6.3–7.0			
Dairy ration	6.8–7.3							
Pasture ration			6.4–7.4				6.1–6.5	
% cultures producing gas	12		17		16		10	
Type of cultural growth*	Fast	Slow	Fast	Slow	Fast	Slow	Fast	Slow
Number cultures grown	55	25	39	3	41	8	19	2
Number cultures producing a pH of:								
5.0 or below	48	6	36	1	39	2	18	0
6.0 or above	6	18	0	2	0	4	0	2
Number coccus cultures	40	0	30	1	36	1	8	0
Number rod cultures	14	25	9	2	4	7	11	2
Number cultures clumping cotton	6	24	4	3	1	7	0	2

* Cultures growing within 48 hours were regarded as fast growers whereas those taking a longer time were classified as slow growers.

types of organisms were present in animals on pasture. Typical organisms found during both winter and pasture feeding are shown in figure 1.

Cultural Results

For convenience the bacteria cultured from rumen contents in this study have been divided into two broad groups: the fast-growing organisms or those which grew within 48 hours, and those which took longer to grow. The fast-growing organisms usually fermented glucose with the production of marked turbidity and high acidity. The slower-growing cultures seldom exhibited much turbidity or lowered the pH of the broth, but they did frequently clump the cotton.

Figure 1. Fiber being broken down by Micro-organisms. Magnification ×450. Note large coccoid forms and tiny slender curved rods at point of breakdown. Organisms typical of those found on winter rations.

Cultural results of these studies showed both broad groups of organisms to be present in all animals on all rations. Generally the glucose-fermenting bacteria were found in the three lower dilutions, showing that they are present in smaller numbers than the slow-growing organisms which appeared in the higher dilutions only after the fast-growing bacteria had been diluted out. Table 1 shows that most of the cultures isolated on all diets grew within 48 hours and that these were predominantly cocci which produced a rather high acidity. An exception to this was the large number of the acid-producing pleomorphic rods which occurred in samples from sheep on pasture. On prolonged incubation there appeared a smaller number of other organisms, mostly rods, which in most cases caused clumping of the cotton without a marked drop in pH.

This general pattern was found in results from both cattle and sheep on pasture, with growth occurring in the hundred million or one billion dilution in 48 hours and then only 1 or 2 cultures growing on further incubation. Cattle and sheep on winter rations gave a similar picture with respect to cultural growth, but there was also a noticeable dietary effect in both species correlated with the amount of grain in the ration. As the amount of grain in the ration increased, there was a corresponding increase in the number of fast-growing bacteria present (see table 2). This in turn caused higher total growth in the samples from animals fed high grain rations. It should be pointed out, however, that as many or more slow-growing organisms ap-

TABLE 2. EFFECT OF AMOUNT OF GRAIN IN RATION ON CULTURAL GROWTH

Amount of grain in ration	Cattle					Sheep				
Growth in 48 hours										
	No. of animals	10^{-7}	10^{-8}	10^{-9}	10^{-10}	No. of animals	10^{-7}	10^{-8}	10^{-9}	10^{-10}
Low	4	3	0	0	0	6	6	4	0	0
Medium	11	11	5	0	0					
High	6	6	6	2	1	6	6	6	5	1
Pasture	11	11	11	5	1	6	6	5	3	0
Total growth										
	No. of animals	15^{-8}	10^{-9}	10^{-10}	15^{-11}	No. of animals	15^{-8}	10^{-9}	10^{-10}	10^{-11}
Low	4	4	3	0	0	6	6	2	0	0
Medium	11	9	6	0	0					
High	6	6	5	5	0	6	6	6	3	2
Pasture	11	11	8	1	0	6	6	4	0	0

peared in rumen contents from animals fed low and medium grain rations as from high.

All but one or two cultures isolated were obligate anaerobes, and these exceptional cultures were facultative anaerobes. Only 10–17 percent of the cultures formed gas, and these were not associated predominantly with any one ration. Ensilage did not seem to cause any marked differences in the rumen bacteria cultured.

In general it would seem that the cultural results from both species on all rations presented a rather uniform picture with the exception of the

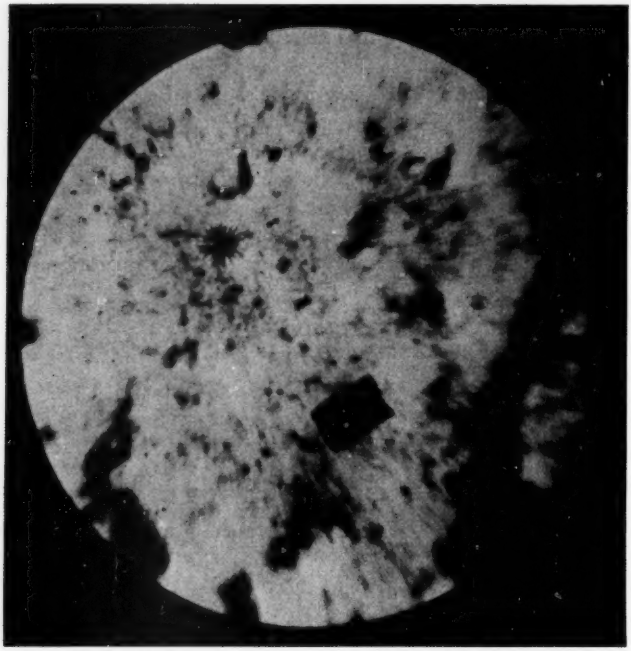

Figure 2. Additional types of bacteria found on summer rations. Magnification ×450. Notice rosette-shaped bacteria and sarcina.

noticeable dietary trend which was correlated with the amount of grain in the ration (see table 1).

pH of Rumen Contents

The pH values of the samples which were not contaminated noticeably with saliva ranged from about 6.3–7.3. Since there was considerable variation within groups and not much between groups, it is difficult to make any significant statement on these findings. However, in this study the animals when on pasture did not have a higher rumen pH than when fed winter rations, and sheep did not have a higher rumen pH than cattle on similar rations (table 1).

Discussion

The purpose of this survey was to determine whether factors normally encountered in farm practices in various geographical regions of a state,

such as Ohio, would influence the bacterial flora of the rumen. The major variables were feed, species, and breed, while other minor factors such as source of water supply, temperature and soil conditions changed inevitably with the geographical location and season.

Judging from the results of the tests made, species and breed within species did not play a major role in influencing the rumen flora. The miscellaneous factors found in change of location did not appear to influence the kinds or numbers of bacteria present in the rumen either. The only variable studied which did seem to influence the bacterial population was ration, and here the changes in flora were not so much qualitative as quantitative. For instance, a high grain ration merely encouraged an increase in a type of organism already present in moderate numbers in the rumen, rather than causing an entirely different type of bacteria. The animals on pasture supported more bacteria in the rumen, but only a few different organisms could be observed in the Gram stain, and these were not the predominating flora. The organisms already present on winter rations merely seem to increase in numbers.

It is recognized that the three technics used in this study may not be sufficiently precise to detect small differences, a limitation which has been discussed in the paper (Gall *et al.*, 1949) describing the methods. There may be differences between some groups of animals studied that these technics did not demonstrate. However, since differences between rations were shown by these methods when a group of animals were on experimental rations (unpublished data), it would seem that large variations could be demonstrated by these methods.

It should also be pointed out that some of the differences which have been detected in these studies are difficult to interpret with the present incomplete knowledge of both the physiology and bacteriology of the rumen.

Potentially the cultural technic is the most valuable of the three. Slide counts and Gram stains yield data about the numbers and morphological types of bacteria present, but only the living bacterium can give real information about its physiology, and thus its probable function in the rumen.

In this study only very incomplete data were obtained on the physiology of the bacteria cultured. It can be postulated, however, that the fast-growing organisms, because of their ability to break down glucose, can utilize the starch and other soluble carbohydrates in the rumen, while the slower growing bacteria, which clump the cotton, may be the cellulose digesters. This assumption is further supported by observing the Gram stains, on which it can be noted that organisms of the same morphological type as the slow-growing cultures are seen attached to the fiber, while the bacteria re-

sembling the fast-growing cultures remain free on the slide. Until these cultures are tested for these characteristics, there is no proof of these assumptions.

The physiological studies will be greatly facilitated when the cultural technics are improved so that all of the predominating bacteria present in the rumen may be readily grown. Especial attention must be paid to the cellulose-digesting organisms, which always have proven more difficult to culture.

It should be pointed out that all of the rumen samples studied were composed of solid material of rather high dry matter, and are not representative of liquid rumen contents or of samples of rumen contents of low dry matter. This should be kept in mind when interpreting the results.

It has been stated by Hastings (1944) in his review article that the pH of the rumen of sheep is more alkaline than that of cattle and it has therefore been assumed that the bacteria present in the two species would be different. In these studies the pH of the rumen of the two species was similar when the animals were fed the same type of ration. This was also true of the bacterial population, as has been noted above.

The effect of ensilage on the pH of the rumen contents and on the bacteria in the rumen has often been a subject of speculation. The results of these studies have not indicated that ensilage has any marked effect upon either pH or bacterial flora of the rumen.

Summary

Rumen bacteria of 21 cattle and 12 sheep on practical winter rations and 11 cattle and 6 sheep on pasture were studied by means of direct slide counts, Gram stains and anaerobic cultural technics.

Bacterial slide counts on rumen contents from cattle and sheep on the several winter rations averaged about 50 billion per gram of fresh rumen contents, while cattle and sheep on pasture averaged 96.1 billion and 85.4 billion respectively.

The bacterial picture as seen on Gram stains from cattle and sheep on the several winter rations resembled each other closely; the bacteria from animals on pasture appeared morphologically similar to those on winter ration but a few different types of bacteria were seen in addition.

Cultural results from both species on all rations presented a rather uniform pattern in many respects, but there was a noticeable increase in fast-growing organisms correlated with an increase in the amount of grain in the ration.

Cattle and sheep did not appear to have markedly different bacterial population or rumen pH when fed similar rations.

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THE EFFECT OF INTENSITY OF GRAZING ON PASTURE AND ANIMAL PRODUCTION AT THE DIXON SPRINGS STATION[1]

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INTENSITY of grazing or the degree of forage utilization on any given field or fields is dependent upon many factors as fertility, plant species, rainfall, temperature, and the time of the year when grazing is done. These factors are very complex in their interrelationships, and difficult to analyze. Since it is impossible to control rainfall and temperature, recourse must be had to other means of increasing the length of the pasture season in southern Illinois from the present average length of 100 days up to the potential pasture season of 240 days. The principal tools available for lengthening the grazing season are grazing management, fertilization, mowing to control weeds and undesirable vegetation, and providing supplementary pasture crops.

The Dixon Springs Experiment Station is located on land chiefly rolling, that is best adapted to and used as pasture. This has necessitated the planning of investigations to answer some of the questions arising in this type of agriculture with particular reference to the economy and practicality of operation. The question of economy of operation is best answered by the fact that in most seasons soil erosion is the most serious hazard; without soil treatment, even grassland suffers some soil loss. A saving factor even without soil treatment is a lack of palatable vegetation with subsequent lowered consumption. In the face of this statement, a contradiction is offered; under-grazing of pastures or so-called moderate utilization also increases the amount of unpalatable vegetation after a few years.

This paper presents plant and animal data from experimental fields at the Dixon Springs Experiment Station in southern Illinois.

Climatic Factors

The climate of southern Illinois is marked by greater annual precipitation and higher temperatures than central and northern Illinois. Maturity of some species as Kentucky bluegrass is three to four weeks earlier than in the northern part of the state. The latitude of the Dixon Springs Station is approximately that of central Kentucky. Precipitation figures are given in table 1.

[1] Contribution from the Dixon Springs Experiment Station, College of Agriculture, University of Illinois, Urbana, Illinois.

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TABLE 1. MONTHLY PRECIPITATION* IN INCHES FOR THE GRAZING SEASONS, 1940–1946, INCLUSIVE

Year	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
1940	5.01	4.06	7.64	3.43	1.42	1.57	3.05	1.19	0.60	5.03
1941	0.74	0.80	3.96	1.16	1.82	1.44	4.54	1.96	7.11	2.64
1942	3.68	4.85	6.41	3.90	5.77	3.35	7.63	1.65	2.13	5.11
1943	1.16	7.99	4.33	11.32	2.72	5.80	1.57	3.49	1.83	1.25
1944	3.35	4.62	5.71	3.96	0.81	0.87	2.02	1.38	0.67	1.91
1945	7.45	11.05	8.13	4.57	10.17	2.82	5.81	11.24	1.73	5.40
1946	5.90	1.70	2.35	9.15	0.42	5.20	6.82	1.05	1.68	5.02

* From Soil Conservation Research Station data.

The season of 1944 was particularly dry during the period of July through November. The effect of this drouth period is shown in extremely low forage yields. In contrast, precipitation in 1945 was the highest recorded over a long period of years.

Experimental Methods

Four twenty-acre fields were laid out and fenced in 1937 (figure 1). All fields received a uniform application of four tons of limestone an acre. In addition, the east one-half of fields 1 and 3 received 1,000 pounds of rock phosphate per acre and the west one-half received 300 pounds of 36% superphosphate. Fields 2 and 4 received 1,000 pounds of rock phosphate and 200 pounds of 36% superphosphate per acre on the east one-half and 500 pounds of 36% superphosphate an acre on the west one-half. All fields were seeded with a mixture of Kentucky bluegrass, redtop, and Korean lespedeza. In addition, fields 1 and 3 received seedings of sweet clover and orchard grass. Water for livestock was not available in all fields until 1940 when pipe was laid to each field from an adjacent pond. During 1938 and

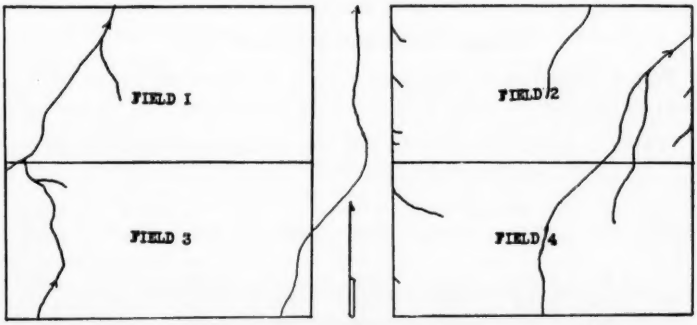

Figure 1. Arrangement of fields.

1939 all fields were used for hay and for grazing by nonexperimental animals. In 1940 the original plan of grazing was initiated. This plan was as follows:

Field 1—Heavy continuous grazing.

Field 2—Moderate continuous grazing. On these fields animals were to be pastured throughout the grazing season.

Field 3—Heavy alternate grazing.

Field 4—Moderate alternate grazing. These fields were grazed and rested alternately.

As indicated in table 6, during 1940 and 1941 the fields were used for relatively short periods, a result of having insufficient numbers of livestock available to adequately stock this experiment. Rainfall was a factor in 1941, primarily because of poor distribution. During the remaining years, through 1946, sufficient animals were available to graze these fields. As in most experiments of this type involving relatively large fields, some juggling of numbers of animals was necessary. Animals were weighed on and off the fields at regular intervals or when a change was necessary.

Forage yields were obtained by the movable cage method, at regular intervals or when sufficient growth accrued to warrant sampling. Ground cover was determined, usually in the late summer, by point quadrat and/or ocular estimate. Excess or/and undesirable vegetation was mowed each fall on all fields.

Hereford cattle, both purebred and grade heifers and steers, and sheep, both ewes and lambs, were used as grazing animals. On alternately grazed fields during the years 1940 through 1944, animals were removed to other pasture during periods of rest. In 1945 and 1946 temporary electric fences were installed on the alternately grazed fields and cattle and sheep alternated between the two halves of each field. Small bands of purebred sheep pastured with the cattle had access to the entire field in the late fall of 1945. In 1946, sheep were the only grazing animal used.

Forage Yields and Botanical Data

Forage yields from all fields in all years in pounds of dry matter per acre were rather uniform (table 2). There were a few exceptions. A low yield

TABLE 2. AVERAGE ANNUAL FORAGE YIELDS IN POUNDS OF DRY MATTER PER ACRE FOR YEARS 1940–1946 INCLUSIVE

Field	1940	1941	1942	1943	1944	1945	1946	7-Year average
1	5,810	2,264	6,384	3,619	1,731	5,648	6,948	4,629
2	5,564	2,098	5,315	6,297	1,670	5,534	5,391	4,553
3	3,854	2,200	6,137	5,566	1,582	4,909	4,924	4,168
4	5,444	2,238	5,752	4,817	2,762	5,148	4,335	4,357

was obtained from field 3 in 1940. This was attributed to heavy grazing in 1939 by nonexperimental animals. The 1943 yields were variable and again the result of grazing management during the previous season. In 1946 large yields of dry matter on fields 3 and 4 were attributable to broomsedge *Andropogon virginicus*, a nonpalatable and undesirable native grass.

During early years of this experiment the percentage of ground cover made by *Andropogon virginicus* was relatively small. Following the season of 1941, when rainfall was deficient in February, March, May, June, and July, a period for favorable grass growth, large numbers of seedlings of broomsedge appeared. Seed sources were plentiful since some unimproved fields in the neighborhood had nearly solid stands. It has always been thought that soil containing sufficient lime and phosphorus would support such a vigorous stand of grass and legumes that broomsedge would not survive. The plant itself is late in maturity, not flowering until late August and September; therefore, its period of growth coincides with the dormant periods in the growth of Kentucky bluegrass and redtop, which in itself is advantageous to seedling establishment and growth of broomsedge.

Management, with respect to numbers of grazing animals, and time of grazing was important and considerable difficulty was encountered in trying to estimate the number of animals to be pastured, and again in estimating the amount of forage that would be available during the ensuing seasons. This resulted in some juggling of animals to fit numbers to the available forage. Because of these difficulties some losses in weight by animals resulted at the expense of previous gains.

From the standpoint of pasture ecology in this area, the management phase is extremely interesting; however, it needs considerable clarification to place it in proper perspective. No data are available relative to the quantities of broomsedge consumed by animals. Certainly it must have been a small amount in comparison to that available. When broomsedge seedlings are three to four inches tall, livestock do pasture this species to some extent. Chemical analyses of the full grown but immature plants show a crude protein content of 5.50%, a calcium and phosphorus content of 0.157 and 0.159% respectively. Even crabgrass, *Digitaria species*, contains higher percentages of these materials.

Through the several years of this experiment botanical analyses have indicated changes in ground cover. Observations only were made in 1940. A summary of botanical analyses indicating vegetational trends and changes are shown in table 3.

A number of comparisons may be drawn from table 4. Wild grasses include chiefly broomsedge *Andropogon virginicus*, crabgrass *Digitaria sp.*, and beadgrasses, *Paspalum sp.* The first named species predominated on fields

TABLE 3. SUMMARY OF BOTANICAL ANALYSES FOR 1941–1946 INCLUSIVE, BY FIELDS

Year	Species and Percentages of Ground Cover							
	Kentucky bluegrass	Redtop	Timothy	Wild grasses	Korean lespedeza	Clovers	Weeds	None
Field 1. Heavy Continuous Grazing								
1941	43.3	4.6	0.1	10.2	14.0	1.3	11.6	14.9
1942	35.6	1.7	0.1	18.8	28.4	3.3	10.1	2.0
1943	51.0	0.4	—	27.3	14.7	0.4	6.2	—
1944	33.5	0.7	—	9.0	2.6	1.7	1.2	52.3
1945	36.0	4.9	—	16.6	27.6	3.8	1.3	9.8
1946	32.3	2.9	—	27.3	7.3	2.6	1.6	25.4
Field 2. Moderate Continuous Grazing								
1941	39.3	12.7	—	20.6	5.6	—	7.5	14.3
1942	20.0	4.2	0.2	16.0	49.5	1.1	7.6	1.4
1943	44.8	2.4	—	25.0	21.0	0.3	6.5	—
1944	31.3	4.7	—	13.1	0.3	—	2.5	48.1
1945	54.7	5.1	—	11.7	24.2	—	2.0	2.3
1946	39.7	3.8	—	18.3	7.6	0.4	1.7	28.5
Field 3. Heavy Alternate Grazing								
1941	38.5	2.8	—	16.7	8.0	1.9	21.9	10.2
1942	30.2	2.3	0.3	15.5	32.8	5.2	12.5	1.2
1943	30.2	6.4	0.4	15.1	30.5	5.8	11.6	—
1944	15.1	12.5	—	15.8	7.7	—	9.2	39.7
1945	38.5	14.3	—	13.4	24.2	2.0	0.6	7.0
1946	27.9	10.2	0.5	26.1	9.1	0.9	3.5	21.8
Field 4. Moderate Alternate Grazing								
1941	45.0	13.3	0.5	13.5	5.3	—	6.4	16.0
1942	32.6	7.3	0.3	12.8	37.9	0.2	7.8	1.1
1943	39.5	1.3	0.3	20.6	29.0	2.5	6.8	—
1944	39.9	3.4	—	22.3	5.3	—	4.6	24.5
1945	58.0	3.5	—	11.4	22.4	1.4	1.0	2.3
1946	38.0	3.4	0.9	21.5	6.2	0.6	1.4	28.0

2 and 4 under conditions of moderate grazing making up most of the figures found under "wild grasses." In 1946, observations indicated that a large part of the vegetation consisted of "wild grasses." They dominate lower growing species, therefore a cursory examination is misleading with respect to ground cover. However, samples of vegetation taken for yield showed a much larger proportion of unpalatable material than indicated by botanical analyses with quadrat readings.

TABLE 4. SUMMARY OF BOTANICAL ANALYSES FOR 1941–1946 INCLUSIVE, BY YEARS

Field	Species and Percentages of Ground Cover							
	Kentucky bluegrass	Redtop	Timothy	Wild grasses	Korean lespedeza	Clovers	Weeds	None
				1941				
1	43.3	4.6	0.1	10.2	14.0	1.3	11.6	14.9
2	39.3	12.7	—	20.6	5.6	—	7.5	14.3
3	38.5	2.8	—	16.7	8.0	1.9	21.9	10.2
4	45.0	13.3	0.5	13.5	5.3	—	6.4	16.0
				1942				
1	35.6	1.7	0.1	18.8	28.4	3.3	10.1	2.0
2	20.0	4.2	0.2	16.0	49.5	1.1	7.6	1.4
3	30.2	2.3	0.3	15.5	32.8	5.2	12.5	1.2
4	32.6	7.3	0.3	12.8	37.9	0.2	7.8	1.1
				1943				
1	51.0	0.4	—	27.3	14.7	0.4	6.2	10.0
2	44.8	2.4	—	25.0	21.0	0.3	6.5	—
3	30.2	6.4	0.4	15.1	30.5	5.8	16.6	—
4	39.5	1.3	0.3	20.6	29.0	2.5	6.8	—
				1944				
1	33.5	0.7	—	9.0	2.6	1.7	1.2	52.3
2	31.3	4.7	—	13.1	0.3	—	2.5	48.1
3	15.1	12.5	—	15.8	7.7	—	9.2	39.7
4	39.9	3.4	—	22.3	5.3	—	4.6	24.5
				1945				
1	36.0	4.9	—	16.6	27.6	3.8	1.3	9.8
2	54.7	5.1	—	11.7	24.2	—	2.0	2.3
3	38.5	14.3	—	13.4	24.2	2.0	0.6	7.0
4	58.0	3.5	—	11.4	22.4	1.4	1.0	2.3
				1946				
1	32.3	2.9	0.07	27.3	7.3	2.6	1.6	25.4
2	39.7	3.8	—	18.3	7.6	0.4	1.7	28.5
3	27.9	10.2	0.5	26.1	9.1	0.9	3.5	21.8
4	38.0	3.4	0.9	21.5	6.2	0.6	1.4	28.0

TABLE 5. AVERAGE ACRE GAINS, ANIMAL PASTURE DAYS PER ACRE, AND ALSO TOTAL ANNUAL DAYS ON PASTURE ON EACH FIELD

Year	Animals	Days pastured	Animal pasture days per acre	Gains lbs./A
		Field 1. Heavy Continuous Grazing		
1940	Cattle	27	27	49
	Sheep	31	160	46
1941	Sheep	73	527	115
1942	Cattle	182	100	131
	Sheep	107	364	78
1943	Sheep	198	1,045	143
1944	Sheep	83	311	99
1945	Cattle	221	110	133
	Sheep		101	
1946	Sheep	148	823	154
Average for 7 years		153	510	135
		Field 2. Moderate Continuous Grazing		
1940	Cattle	27	14	47
1941	Sheep	98	437	43
1942	Cattle	182	137	195
1943	Sheep	177	760	88
1944	Sheep	109	455	92
1945	Cattle	221	119	126
	Sheep		59	
1946	Sheep	148	600	137
Average for 7 years		137	369	104
		Field 3. Heavy Alternate Grazing		
1940	Cattle	21	33	67
	Sheep	20	145	30
1941	Sheep	55	417	104
1942	Cattle	151	184	253
1943	Cattle	68	88	125
	Sheep	52	264	32
1944	Sheep	106	471	163
	Cattle	—	21	1
1945	Cattle	185	137	183
	Sheep		57	
1946	Sheep	148	818	147
Average for 7 years		115	376	158
		Field 4. Moderate Alternate Grazing		
1940	Cattle	21	21	54
	Sheep	20	82	14
1941	Sheep	109	469	109
1942	Cattle	151	146	257
1943	Cattle	69	51	70
	Sheep	49	210	34
1944	Sheep	69	331	142
	Cattle	—	21	48
1945	Cattle	210	97	137
	Sheep		92	
1946	Sheep	148	610	133
Average for 7 years		121	304	143

Korean lespedeza, *Lespedeza stipulacea*, stands and percentages were closely associated with moisture and self-seeding conditions. In 1941 and 1944, both dry seasons, stands of this species were light and scattered. During the remaining seasons excepting 1946, good stands were present. In the latter year insufficient seed from the good 1945 crop was dropped as a result of late fall and early winter pasturing on all fields.

Animal Data

Animal gains, days on pasture, and pasture days show considerable variation between years. In some cases the lack of relationship between forage yields and animal gains is marked. This can best be explained by the fact that in some seasons considerable grazing was done in November, December, and January after the growing season. Animal gains during these months are made on lespedeza seed and dry, mature forage aided by cool weather and lack of insects. A good part of this experiment was conducted before DDT insect sprays were available. Most of the animals pastured at this time of the year are better quality because the cull sheep and cattle have been sent to market.

Table 5 shows animal gains, days on pasture, and pasture days per acre each year. Period gains and period forage yields are available; however, space limitations do not permit their inclusion here.

During the seven-year period an attempt was made to pasture the respective fields either heavily or moderately by increasing or lessening the number of animals. Annual gains by animals per acre fluctuated more because of this factor than from types and availability or lack of forage.

Conclusions

The differences in animal gains resulted more from rates of stocking than from variations in kinds and amounts of forage available; however, it follows rather closely the trend of experimental work conducted by Van Doren *et al.* (1940) on Soil Conservation Service Research Station runoff plots at Dixon Springs, particularly with respect to animal gains and ecological factors. From the standpoint of practical usage on the farm or range, utilization of an electric fence or other temporary barrier on the same field, such as was used during 1945 and 1946 in this experiment, would facilitate alternate grazing of fields.

Since most of the animal gains are made during the early months of the season, and again during the cool fall periods of grazing, largest animal returns are obtainable through heavy alternate grazing or a system making the best use of the more succulent forage. During the period from mid-July to mid-September gains were relatively small because of high temperatures, or flies, or both, coupled with less succulent forage.

Although moderate grazing has been recommended by most people engaged in range research it is a question that cannot be answered by the same recommendation in the humid areas. Obviously, that which is considered as moderate or heavy grazing in one season may not be the same during the next year. Therefore, it seems desirable to graze judiciously or to the point where enough top growth remains to protect crown and rhizome buds of forage species during the winter months and still not so tall that smothering takes place.

Botanical analyses were valuable adjuncts in determining carrying capacity and forage utilization. Also they provided a basis for future improvement in methods of study of pasture ecology.

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CALIFORNIA PSYCHROMETRIC CHAMBER FOR LIVESTOCK ENVIRONMENTAL STUDIES[1]

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A CHAMBER for studies of the effect of various conditions of environmental temperature, humidity, and air movement on the growth and well being of farm animals was constructed by the University of California at Davis, California, in 1928.[3] Various changes in the room itself, the air conditioning equipment, and the operating procedure have been made since that time. This paper will describe the chamber as it is now.

The psychrometric chamber consists of (a) an inner chamber where the animals are housed (see figure 1), (b) an outer or surrounding chamber with a space between the two, varying from two to five feet in width, and (c) the air conditioning equipment. All are located inside of the Animal Science Building.

Inner Chamber

The inside measurements of the inner chamber are 9′×14′×7′4″ high. Triangular air inlet ducts constructed in each corner of the room bring the floor area down to 119 square feet and the volume of the room to 892 cubic feet. The walls of the inner chamber are of 2-inch wood framing supporting insulation of 2 inches of sheet cork, waterproofed on both sides with an asphaltic sealer. The outside is plastered with ½-inch Portland cement and the inside lined with 24-gauge galvanized iron soldered throughout. A double-glazed window on the north side 2′6″×3′4″ serves for observing the animals from the laboratory without disturbing them by entering the chamber. The ceiling is also wood framed and contains two double-glazed light wells giving a glass area of 34 square feet. Electric lights above these windows provide light in the chamber. The remainder of the ceiling is insulated with two inches of sheet cork, sealed with an asphaltic sealer. The lower side of the ceiling is lined with 24-gauge galvanized iron.

A sub-floor of 2″×6″ tongued and grooved flooring is laid on 2″×12″ joists on 14″ centers and insulated with two inches of sheet cork between joists, beneath the wood flooring. As originally constructed, the wood

[1] This paper is a result of a cooperative project between the Division of Farm buildings and Rural Housing, Bureau of Plant Industry, Soils, and Agricultural Engineering U.S.D.A., and the Divisions of Animal Husbandry and Agricultural Engineering of the University of California.

[2] Assistant Professor of Animal Husbandry; Agricultural Engineer, Bureau of Plant Industry, Soils and Agricultural Engineering; and Professor of Animal Husbandry.

[3] The equipment described in this paper was constructed as a result of the ideas and planning of W. M. Regan and G. H. Hart of the Division of Animal Husbandry.

flooring was covered with 14-gauge galvanized iron. However, this was was found to be too slippery for the animals to stand on and a layer of cork brick set on edge in mortar was laid over the sheet iron. After several years use the cork became worn down between the mortar joints by the animals' feet. In 1946 to facilitate cleaning, the bricks were overlaid with a two-inch

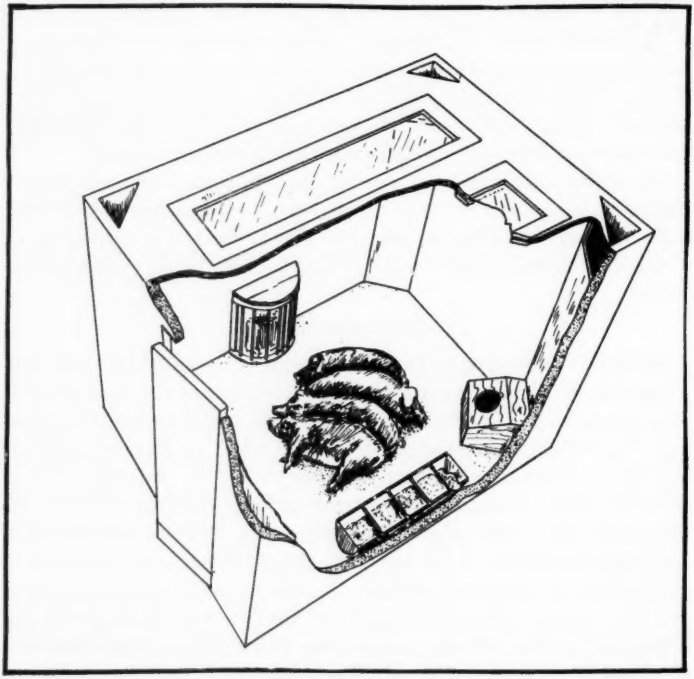

Figure 1. Diagram of inner chamber showing hog watering device, feed trough, cage for recording hygrothermograph, light wells in ceiling, and air inlets from triangular ducts (indicated as open at top to show construction).

layer of concrete with a broomed wearing surface. The floor slopes to a drain near one end of the chamber. Access to the chamber is through an insulated 3′6″ × 6′6″ refrigerator type door located in one end.

Four air inlets are located in the walls near the ceiling, one in each corner of the room. Two outlets are provided, both in the north wall, slightly below the inlets. This arrangement seems to provide a rather uniform air circulation.

Outer Chamber

The outer chamber is for the purpose of providing an enclosure in which the air temperature on the outside of the animal chamber can be maintained at approximately the same temperature as on the inside. This lowers heat loss through the walls and insures that wall temperature, which controls radiation to and from the animals, is about the same as the air temperature. The outer chamber also serves as a "heat lock" when the animal chamber is entered, and provides an area where the animals can be weighed, the instruments store, etc., at the same temperature as the environment being studied.

The walls of this outer chamber are very well insulated, being of 4-inch self-sustaining solid cork, waterproofed and plastered on both sides with asphaltic sealer and ½-inch Portland cement. The ceiling, supported on a wood framework, is of similar construction and contains two light wells for transmitting light from the outside to the inner chamber. The floor of the outer chamber is four inches of corkboard, laid in hot asphalt on the concrete laboratory floor. Access to the chamber is through another cold storage door, 3′6″×6′6″.

The space in one end of the outer chamber is used for housing a two-section brine coil made up of about 800 feet of 1¼-inch galvanized pipe. A small centrifugal fan directly connected to a ⅙ horsepower 220-volt 3-phase motor draws warmed air through these coils and forces the cooled air across the space between the celings, down the side compartments, back through the joist spaces beneath the floor, and finally back to the cooling coils again. This constant circulation maintains the air temperature in the outer chamber at a uniform level, and by manual adjustment of the valves controlling the flow of brine through the coils, a reasonably good adjustment of temperature may be made.

Watering Device for Hogs

While the chamber has been used for studies with both dairy animals and swine, the writers at the present time are concerned mainly with the reaction of swine to their environment. It was soon found that moisture on the floor must be considered as a very important part of the hog's environment and, in order to determine the effect of other environmental variables such as ambient air temperature and relative humidity, the floor must be kept dry. A watering device, shown in figure 1, was developed that has proven entirely satisfactory in preventing splashing and wastage of water, and in measuring the amount of water used. A galvanized metal tank, about two feet square and covered tightly except for a circular drinking hole, is provided with a float and valve to maintain the water at the correct level.

A metal partition, open at the bottom, separates the float compartment from the drinking compartment, to prevent the hogs from working the float and to cut down splashing. A series of interchangeable plates of $\frac{1}{8}$ inch thick metal, with holes 4, 5, 6, and 7 inches in diameter, are provided so that a hole can be selected just large enough to let the hog drink comfortably but not large enough to let it splash water onto the floor. A galvanized iron tank, 20 gallons in capacity, with a glass sight gauge to measure the volume of water in the tank, is located directly above the watering device. The sight gauge has been found more accurate in measuring the amounts of water used than was a water meter, at the low rates of flow. Locating the tank in the chamber itself has another advantage in that it insures that the temperature of the water consumed is always within a few degrees of the room temperature.

Air Conditioning Equipment

The desired temperature and relative humidity in the inner or animal chamber is obtained by cooling or heating the ventilating air. There are no cooling or heating coils in the animal chamber itself. Air is drawn from the chamber through the two outlets by a fan, forced through a dehumidifier consisting of two banks of sprays, to bring the dew point to the desired level, and then reheated by passing through an Aerofin steam heater designed for five pounds pressure. After leaving the heater, the air passes through four insulated ducts to the inlets into the room.

Two tanks for cooling the dehumidifier liquid are located in the basement so that either sweet water or brine can be used, depending upon the conditions desired in the chamber. Ordinarily, sweet water is used at air temperatures of 70° F. and above, and salt brine for lower temperatures. Ammonia is used as the refrigerant in both cases. The sweet water tank, $5'6'' \times 13'0'' \times 6'0''$, has approximately 800 feet of $1\frac{1}{4}$-inch ammonia pipe for cooling surface, the ammonia flow being controlled by a thermostat in the water. This water can be kept at any temperature between 35 and 60° F. An agitator is provided for uniform cooling. The brine system consists of a smaller cylindrical tank, $4'4''$ in diameter and $5'4''$ deep, used in connection with a shell and tube cooler through which the brine is circulated. The liquid temperature can be maintained at any level between 20 and 50° F. when using salt brine (sodium chloride).

A model 400-B Parker Compressor Unit, consisting of a $4\frac{1}{2}'' \times 4\frac{1}{2}''$ twin cylinder ammonia compressor and $7\frac{1}{2}$ horsepower motor, with the necessary condensers, receivers and valves, is used for the refrigeration of the dehumidifier liquid. In case this system goes out of order, the cooling load can be taken over quickly by the regular Animal Science Building refrigeration equipment.

Controls and Limits

The relative humidity of the air going into the chamber is controlled by the dew point of the air coming from the sprays and by the amount of reheating. The spray temperature is maintained at the desired level by the tank-type thermostats mentioned before. The dry-bulb temperature of the chamber air is also maintained by the amount of reheating in the Aerofin steam heater. A Taylor Thermo-tyme regulator in the laboratory controls the steam flow through this heater, by activating a direct acting diaphragm valve.

The amount of air recirculated through the chamber is varied by hand-operated gates in the ducts. If desired, part or all of the air may be taken from outside the building.

Experience has shown the necessity for having safety controls to prevent overheating the animals in the event of mechanical trouble. At the present time, the chamber is equipped with a thermostat in series with a solenoid operated steam valve which will shut off the steam if the chamber temperature rises several degrees above the desired temperature. In addition, failure of the air pressure in the control lines between the Thermo-tyme regulator and the steam diaphragm valve automatically shuts off all steam by closing a back-acting diaphragm valve.

Using salt brine in the dehumidifier, the effect of temperature on hogs (in groups of four or less) has been studied between 40 and 120° F. (Heitman and Hughes, 1949; Kelly, Heitman and Morris, 1948). When most of the air is recirculated, these conditions can be obtained any time of the year due to the heavy insulation used in the chamber. Forty degrees F. is about the lower limit, using salt brine, but 130° F. could be obtained if necessary. At the lower temperatures, relative humidities in the chamber varying from 50% to 95% can be kept, and at the higher temperatures from 10% to 95%. The Thermo-tyme regulator is fitted with a clock which can also be made to operate specially cut cams for studying the effect of diurnal changes in temperature and relative humidity.

Summary

The construction and operation of a chamber for studying the effect of different conditions of environmental temperature, humidity, and air movement on livestock, with special reference to swine, has been briefly described.

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PANTOTHENIC ACID DEFICIENCY IN PIGS FED DIETS OF NATURAL FEEDSTUFFS[1]

R. W. Luecke, F. Thorp, Jr., W. N. McMillen and H. W. Dunne[2]
Michigan Agricultural Experiment Station

IT IS well known that the pig requires pantothenic acid. A review by Ellis (1946) summarized the pertinent literature concerning pantothenic acid and its relationship to the nutrition of the pig. With the advent of synthetic calcium pantothenate both Hughes (1942) and Wintrobe *et al.* (1942) demonstrated that the feeding of a pantothenic acid-free ration to pigs resulted in a loss of appetite, lowered growth rate, loss of hair, diarrhea, an ulcerated condition of the large intestine and an abnormal gait characterized as "goose-stepping." Previous to the work with synthetic calcium pantothenate Chick *et al.* (1938) were able to produce muscular incoordination in pigs fed a purified ration which contained all of the then known B-vitamins and the "eluate factor" (pyridoxine). The paralytic symptoms produced were prevented by including the "filtrate factor" (pantothenic acid) in the ration. Ellis and Madsen (1941) produced locomotor incoordination in pigs fed rations composed of natural feedstuffs. Both the incidence and severity of the disease were increased by heating the ration prior to feeding. Ellis *et al.* (1943) later found that pantothenic acid was effective in preventing the deficiency when the heated ration was fed.

Since posterior paralysis is known to occur under field conditions (Wehrbein, 1916; and Doyle, 1937), it seemed desirable (1) to determine whether pantothenic acid deficiency could be produced by feeding rations made up largely of corn and (2) to determine whether the pantothenic acid content of the diet is reflected in the levels of this factor found in the blood and urine. Moreover, it would be of interest to study the effects of pantothenic acid-low rations on the daily gain in body weight and efficiency of food utilization.

Experimental

Pigs used in the experiment were of two breeds. In lots 1 and 2 Hampshire pigs were used and lots 3 and 4 consisted of Duroc Jersey pigs. Approximately ten days before the pigs were placed on experiment they were vaccinated for hog cholera by the serum and virus method. The two rations used in the experiment are shown in table 1. The crude protein con-

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tent of rations A and B was 15.8 and 16.2% respectively, and the pantothenic acid content was 3.82 and 3.42 mg. per pound respectively, as determined microbiologically by the method of Skeggs and Wright (1944). The samples of feedstuffs were prepared for assay according to the method of Buskirk *et al.* (1948). In addition, rations A and B were supplemented with thiamine, riboflavin, nicotinic acid and pyridoxine in the amounts indicated in table 1. A vitamin A and D concentrate (Quadrex) was added to both rations in amounts which supplied 2,000 I.U. of vitamin A and 200 I.U. of vitamin D_2 per pound of feed. The composition of the complex mineral mixture was the same as that described by Luecke *et al.* (1947). All of the pigs were kept on concrete floors, bedded with wood shavings and were self-fed.

TABLE 1. COMPOSITION OF THE PANTOTHENIC ACID-LOW RATIONS[1]

Constituents of ration	A	B
	%	%
Corn	86	87
Casein (commercial)	5.5	10
Soybean oil meal (expeller)	5.5	
Complex mineral mixture	3	3

[1] The following vitamins were mixed with both rations (values expressed in mg. per lb. feed): thiamine, 5; riboflavin, 5; nicotinic acid, 15; pyridoxine, 2.5. Choline chloride was also added to both rations at a level of 0.1 percent.

Results and Discussion

Growth Studies

Up to the time of weaning, the pigs which comprised lots 1 and 2 had been kept on alfalfa pasture. Pigs in lot 1 were fed ration A to which calcium pantothenate had been added at a level of 15 mg. per pound of feed. The growth response of these pigs is shown in table 2. It can be seen that the pigs in lot 1 gained an average of 0.91 pounds daily while consuming an average of 1.95 pounds of feed. It required 2.14 pounds of feed to produce a one pound gain in body weight. The pigs in lot 1 appeared normal in every respect.

Pigs in lot 2 were fed ration A. An examination of the growth response of these pigs (table 2) indicates that while the pigs in lot 2 consumed only slightly less feed than the animals in lot 1 there was a significant decrease in the average daily gain in body weight. This is also reflected in lowered efficiency with which the pigs in lot 2 converted feed to body weight gain. By the third week the only symptoms of deficiency were rough hair coats and an unthrifty appearance. At the beginning of the seventh week, two of the pigs in lot 2 showed an abnormal gait and by the end of the eighth week,

five of the six animals showed typical symptoms of lameness and incoordination. At the end of the eighth week, three of the pigs were autopsied and a pathological study was made of the affected tissues. The remaining two pigs were kept on the same ration for an additional four weeks. The incoordination became progressively more pronounced; however, in no case was complete paralysis of the hind quarters observed.

The Duroc Jersey pigs used in lots 3 and 4 were kept in concrete pens up to the time of weaning, and creep-fed a presumably adequate ration. The weanling pigs appeared to be in good condition when placed on the experiment. The pigs in lot 3 were fed ration B (table 1) which contained supplementary calcium pantothenate in the amount of 15 mg. per pound of ration. The animals in this lot gained an average of 1.10 pounds per day from the consumption of 2.50 pounds of feed. It required only 2.27 pounds of feed per day to produce a one pound gain in body weight (table 2). The increased gains in body weight of the pigs in lot 3 over the animals in lot 1 is probably due, in a large part, to the difference in breed rather than to a difference in the rations.

TABLE 2. RESPONSE OF PIGS FED THE VARIOUS EXPERIMENTAL RATIONS

Items compared	Lot number			
	1[1]	2	3[1]	4
Ration fed	A	A	B	B
Number of pigs	5	5	6	6
Initial age in weeks	6	6	6	6
Number of weeks on trial	8	8	8	8
Average initial weight (lbs.)	23	23	24	25
Standard deviation of initial weight	1.0	1.3	2.6	3.4
Average daily gain (lbs.)[2]	0.91±.06	0.68±.06	1.10±.10	0.75±.21
Average daily feed consumption (lbs.)	1.95	0.88	2.50	2.32
Lbs. of feed per lb. of gain	2.14	2.76	2.27	3.09

[1] Pigs in lots 1 and 3 received supplementary calcium pantothenate at a level of 15 mg. per lb. of ration.
[2] Difference in daily gains between lots 1 and 2 and difference between lots 3 and 4 are statistically significant.

Ration B was fed to the pigs in lot 4. During the third week of the experiment, one of the pigs in this lot developed diarrhea and by the end of the fourth week, four of the six pigs had very severe diarrhea. The animals became very dirty and unthrifty in appearance. The diarrhea did not last longer than two weeks in any case, and had stopped completely by the end of the sixth week. The appetite of the pigs, which had decreased considerably during this period, was regained and during the last two weeks of the experiment, the pigs in this lot actually consumed 20% more feed than did the animals in lot 3. The feed consumption data of lot 4 for the entire experi-

mental period obscure these variations so that on the average the pigs in lot 4 consumed only slightly less feed than did the pigs in lot 3. As soon as the diarrhea in the lot 4 pigs had stopped, symptoms of incoordination were noticed and by the end of the seventh week, all of the pigs were affected with some degree of lameness. The degree of lameness varied from moderate to severe; however, as in lot 2, complete paralysis was absent. The presence of diarrhea in four of the pigs in lot 4 is difficult to explain since no diarrhea was observed in lot 2. Ellis and Madsen (1941) did not report symptoms of diarrhea in any of their studies of pantothenic acid deficiency. However both Wintrobe *et al.* (1942) and Hughes (1942) using purified rations which were supposedly free of pantothenic acid, reported that one of the most prominent symptoms of pantothenic acid deficiency was very severe diarrhea. One possible reason for the differences observed between lots 2 and 4 may be due to the difference in previous nutritional treatment. Animals from lot 2 were taken from alfalfa pasture, whereas the pigs in lot 4 had been creep-fed on a supposedly adequate ration made up of natural feedstuffs which included ground alfalfa hay but had been kept on concrete. The pigs in lot 2 may have possessed a greater storage of pantothenic acid than the animals in lot 4. Another possibility may be that of a breed difference in the requirement for pantothenic acid. The Duroc Jersey pig is a more rapidly growing animal than the Hampshire and thus may have a higher requirement for this vitamin. It does not seem possible that the small differences in the pantothenic acid content of the two rations could account for the more severe symptoms of the deficiency observed in lot 3.

Pantothenic Acid in the Blood and Urine

During the last week of the experiment all of the pigs were placed in metabolism cages and a 24-hour urine collection was obtained. The daily excretion of pantothenic acid was obtained by using the previously mentioned microbiological method. Determinations of pantothenic acid in whole blood were made only from the pigs in lots 3 and 4. The blood was drawn by syringe and needle from the anterior venous sinus and prepared for assay by the method of Ray *et al.* (1947). Table 3 shows the daily urinary excretion of pantothenic acid together with the pantothenic acid content of whole blood. It can be seen that there are large differences in pantothenic acid excretion between the two lots which received pantothenic acid and those which did not. However, in any case the amount of pantothenic acid recovered in the urine represents only a very small part of the amount ingested. Pigs in lots 1 and 3, which received supplementary panthothenic acid showed a wide range in the urinary excretion of this vitamin. On the other hand, pigs from lots 2 and 4, which received no supplementary pan-

tothenic acid, do not show the same wide variations in the excretion of this vitamin. The blood levels of pantothenic acid within lots 3 and 4 are surprisingly uniform and the differences obtained between lots 3 and 4 are undoubtedly significant. Whether the pantothenic acid content of pig blood as shown for lot 4 (table 3) will serve as a diagnostic criterion of pantothenic acid deficiency remains to be determined. In the case of the chicken, Pearson *et al.* (1946) have found that differences in the level of pantothenic acid in the feed are reflected in the blood levels of this vitamin.

TABLE 3. PANTOTHENIC ACID IN BLOOD AND URINE

Lot No.	Urinary excretion	Blood
	mg./24 hrs.	μg./ml.
1	4.14[1] 1.80–9.28[2]	—
2	0.49 0.37–0.79	—
3	4.11 1.40–8.85	0.64 1.38–1.82
4	0.34 0.19–0.52	0.89 0.77–1.06

[1] Average.
[2] Range.

Pathology

At the end of the experimental period, three pigs from lot 2, three from lot 4, and one each from lots 1 and 3 were autopsied. The sciatic nerve was removed immediately after death, fixed in 10% neutral formol-saline solution, processed, and embedded in paraffin. The tissue sections were stained with hemotoxylin-eosin. The myelin sheaths were stained by Wolters' modification of the Weigert method as described by Mallory (1938). The sections from the pigs in lots 2 and 4 showed swollen fiber tracts which were quite granular in appearance and vacuoles were often observed in these areas. Myelin clumps varying in size were seen in the nerves from the affected pigs. In the Weigert (Wolters' modification) stained tissues, vacuoles were present where myelin sheath degeneration had taken place. These vacuoles undoubtedly indicated fat deposits since the frozen sections of formalin-fixed tissues stained with Sudan IV showed fat globules of various sizes along the fiber tract. These pathological changes were similar to those described by Wintrobe *et al.* (1940), Ellis and Madsen (1941), and Wintrobe *et al.* (1942) for pantothenic acid deficiency in the pig. No pathological lesions were observed at autopsy in tissues from the pigs in lots 1 and 3.

Summary

A basal ration of corn, casein, soybean oil meal and minerals contained insufficient pantothenic acid to prevent symptoms of locomotor incoordination and myelin degeneration from appearing. When the same ration was supplemented with calcium pantothenate good growth was obtained as well as an increased efficiency of food utilization. Symptoms of locomotor incoordination did not appear until the seventh week of the experiment.

Severe diarrhea followed by locomotor incoordination was obtained when the pigs were fed a basal ration of corn, casein and minerals. The possible reasons for the more severe symptoms of pantothenic acid deficiency in the second experiment are discussed.

Urinary excretions of pantothenic acid showed wide variations while the blood levels of this vitamin were very uniform within each group.

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SLIDE RULE FOR CALCULATING THE LENGTH OF GESTATION[1]

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CALCULATION of the gestation length from known breeding date to known birth date using a "days of the year" table becomes rather cumbersome and tedious if many such calculations are to be made. A simple device that makes the chore less tedious and increases accuracy of computation is described here. It was devised for use with swine but the same principle can be applied to gestation periods of other classes of livestock and to plant data such as "days to flowering" etc.

Using paper ruled evenly in columns and lines, set down in the first column the daily dates of the breeding season, then skip a column and set down in the third column and opposite each date in the first column the date exactly 115 days later. The number, 115, is chosen because it is close to the mean gestation length for swine. Cut off a blank column of the paper and mark each space in numerical order, starting with number 100 in the case of swine. The numbers 100 to 130 are ample. Place this short numbered column in the empty column between the column of breeding dates and the column of farrowing dates. Set the base number 115 opposite the known breeding date. Then look in the right hand column for the known farrowing date. The figure on the sliding short numbered column opposite the farrowing date is the gestation length in days. When leap year is involved use 116 on the slide as the base number, rather than 115, in the case of animals bred before February 29 and farrowing after February 29.

As illustrated in figure 1, a sow bred on November 21, and farrowing on March 19 of an ordinary year would have a gestation length of 118 days.

If the records have been tabulated in chronological order according to date of birth, it is more efficient to invert the slide, setting the base number on the farrowing date in the right hand column and reading the gestation length on the slide opposite the breeding date in the left hand column. This eliminates much of the up and down motion necessitated by the normal fluctuation of breeding dates for any one given birth date. This is illustrated in the accompanying diagram where a ewe lambing on February 15 and bred on September 21 had a gestation length of 147 days. Note that the base number in the case of sheep is 150 and that the difference between breeding and birth date columns is 150 days.

[1] Journal Paper No. J1613 of the Iowa Agricultural Experiment Station, Ames, Iowa, project No. 32.

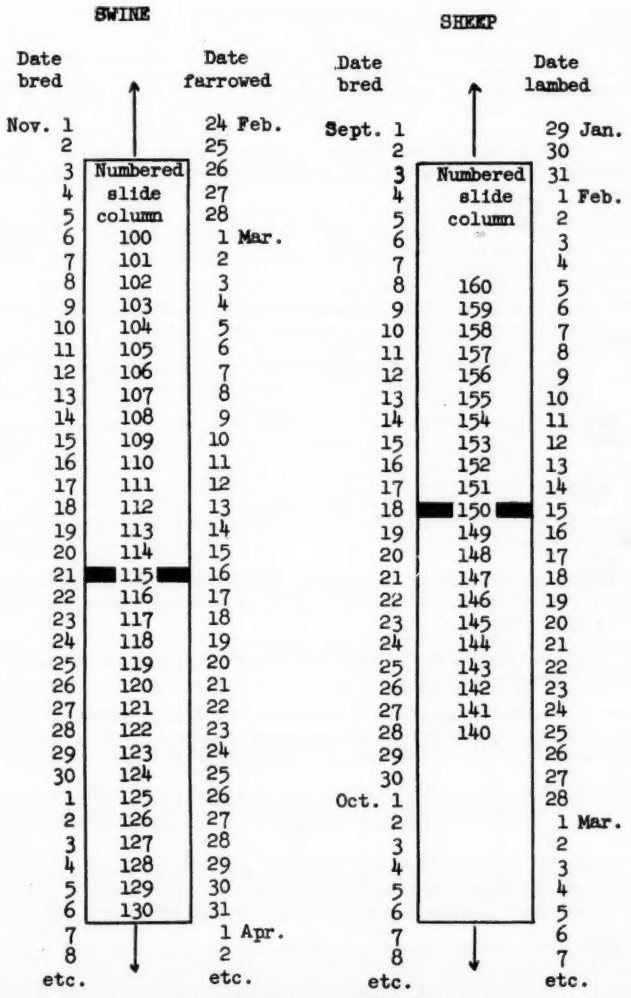


Figure 1. Illustrates two manipulations of the slide rule. The one for swine is for use when the data are recorded chronologically by breeding dates. Set the slide with the base number 115 opposite the known breeding date in the left hand column. The gestation length is the number on the slide opposite the known farrowing date in the right hand column. The illustration for sheep shows the inverted slide for use with data recorded chronologically by date of birth. Set the slide with the base number 150 opposite the known lambing date in the right hand column. The gestation length is the number on the slide opposite the known breeding date in the left hand column.

NEWS AND NOTES

Floyd Andre, formerly with the U.S.D.A. and more recently in administrative work at the University of Wisconsin, became Dean of Agriculture and Director of the Experiment Station and of the Extension Service at Iowa State College effective July 1, succeeding H. H. Kildee, retired.

W. V. Lambert, has been named Director of Extension Service, University of Nebraska, in addition to his duties as Dean of the Agricultural College and Director of the Experiment Station.

George G. Gibson, former extension dairyman, has been made Director of the Extension Service, Texas A. and M. College, to fill the vacancy caused by Ide P. Trotter's transfer to the deanship of the graduate school.

Neal W. Hilston, is now head of the animal production department, University of Wyoming, filling the vacancy created by the resignation of F. S. Hultz.

W. J. Loeffel, chairman of the Animal Husbandry Department, University of Nebraska, has been appointed a member of the agricultural board of the National Research Council.

William E. Morgan, former president of the Arkansas A. and M. College, has been made president of the Colorado A. and M. College at Fort Collins, to succeed I. E. Newsom, retired.

W. W. Burr, emeritus dean of agriculture, University of Nebraska, recently spent three months in several Latin American countries in behalf of agricultural improvement for the Department of State.

Roud McCann, Director of the American Dry Milk Institute and former Director of Extension, Colorado A. and M. College, died on March 17, 1949. B. W. Fairbanks is temporarily filling the vacancy.

S. P. Swenson, a graduate of the University of Minnesota, has been named Dean of Agriculture at Washington State College.

Roger B. Corbett, Associate Dean of Agriculture, and Associate Director of Extension Service, University of Maryland, has been appointed agricultural counsel for the National Association of Food Chains, Washington, D. C., succeeding C. B. Denman, resigned.

Robert H. Burns, head of the Wool Department, University of Wyoming, was one of a group of seven agricultural scientists that made a study of economic conditions in Iran this spring.

A. G. Pickett, member of the animal husbandry staff, Kansas State College, has been named to the post of livestock sanitary commissioner for Kansas effective August 1. Mr. Pickett succeeds Will J. Miller, who resigned after twelve years occupancy of the position.

U.S.D.A. Honor Awards. Among those receiving awards from the Secretary of Agriculture on May 17, 1949, in Washington for service beyond the call of duty were the following: Charles A. Cary, Bureau of Dairy Industry (for distinguished service); William A. Billings, Extension veterinarian, University of Minnesota (for superior service); William A. Craft, Director, Regional Swine Breeding Laboratory, Ames, Iowa (for superior service); Arthur M. Hartman, Bureau of Dairy Industry (for superior service); Enos J. Perry, Extension dairyman, New Jersey College of Agriculture (for superior service). Unit awards were also made to the division of dairy herd improvement investigations, Bureau of Dairy Industry; and to the U. S. Sheep Experiment Station, and the Western Sheep Breeding Laboratory of the Bureau of Animal Industry at Dubois, Idaho.

R. M. Chapline of the U. S. Forest Service and N. R. Ellis of the Bureau of Animal Industry are among the delegates officially designated to attend the International Grasslands Conference in Holland this summer.

Gerald M. Kerr, graduate of Utah State College, has been made Chief of the Division of Grazing, Bureau of Land Management, U. S. Department of the Interior, succeeding J. Will Robinson, resigned.

R. C. Ashby, of the Animal Science Staff, University of Illinois, is teaching a six-weeks' course in livestock marketing at the Utah Agricultural College summer school at Logan in June and July. This fall Dr. Ashby will become head of the new Livestock Marketing Department of Morningside College at Sioux City, Iowa.

Wayland Rhoads, formerly extension animal husbandman, University of Kentucky, and during the war with the War Department in Europe, recently left this country for a one to two year assignment as agricultural advisor in Greece under E.C.A.

Charles B. McConnell, a graduate of Utah State Agricultural College, has been appointed to the animal husbandry staff of the New Mexico A. and M. College.

W. J. Sheely, extension animal husbandman, University of Florida, retired May 1 after more than twenty years service.

Robert A. Edgar, who holds degrees from University of Illinois and Kansas State College, has been made assistant professor of animal husbandry at the Virginia Polytechnic Institute.

Noel F. Titus has been named secretary of the American Berkshire Association to succeed C. W. Mitchell who resigned.

Marshall C. Hervey, associate animal husbandman, University of Tennessee, recently resigned to become professor of dairying at the University of Minnesota.

A. A. Spielman, head of the Animal Industries Department, University of Connecticut, has been appointed associate director of the Storrs Agricultural Experiment Station effective July 1. He will be succeeded by F. I. Elliott of the Animal Industry Department, North Caroline State College.

"Livestock Management," a text book by Coffey and Jackson published by J. B. Lippincott Co., is out in a revised edition of 500 pages.

Leon Pope, with degrees from Michigan State College and Oklahoma A. and M. College, recently became an animal husbandry staff member at the latter institution.

Edward N. Wentworth, director of Armour's Livestock Bureau, was presented a silver water service by the National Wool Growers' Association at its last annual meeting in recognition of his services to the sheep industry, especially the writing of "The Shepherd's Empire" and "America's Sheep Trails."

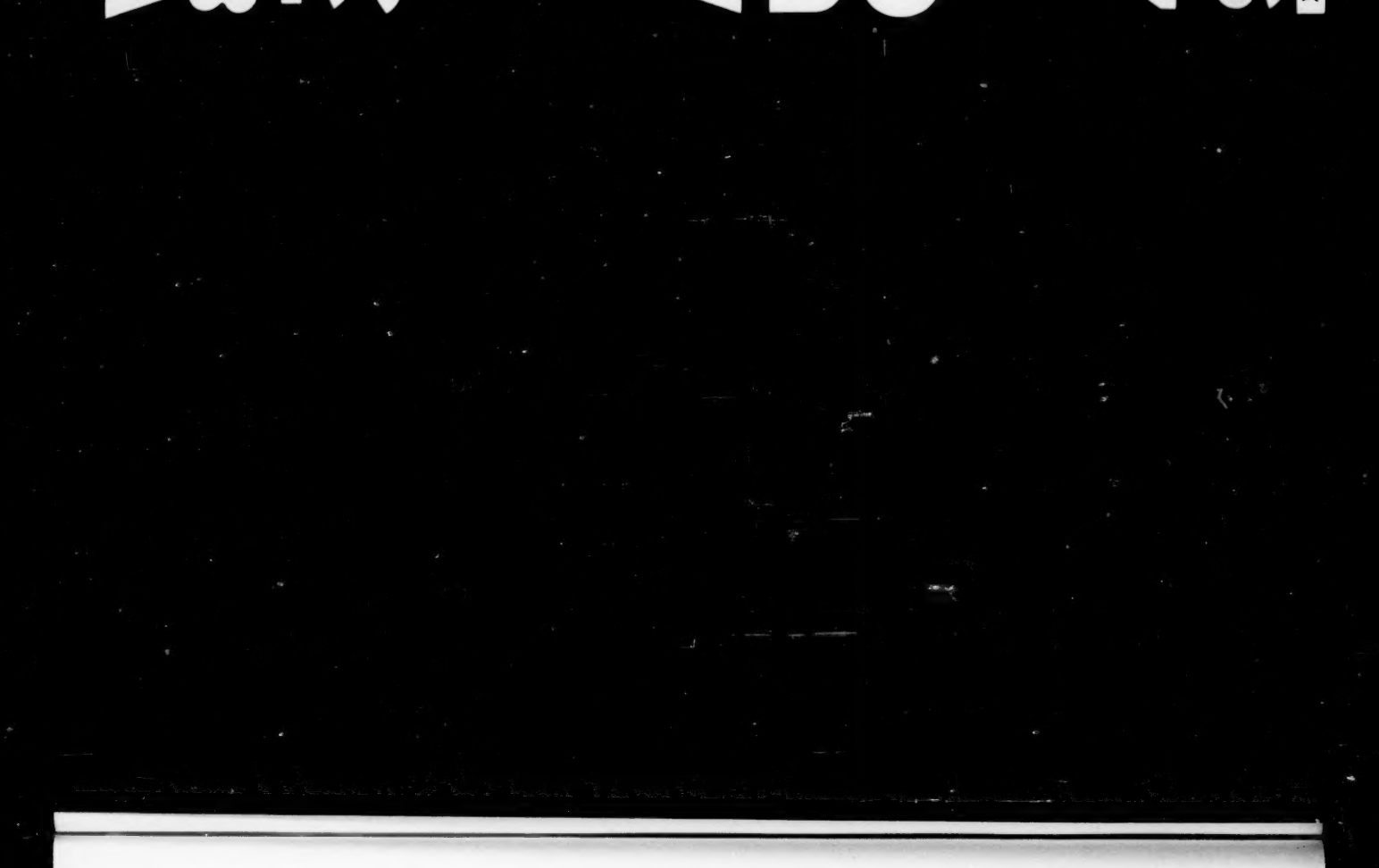
Burl Winchester, formerly on the animal husbandry staff, North Dakota State College, is now engaged in the breeding of Purebred cattle and the management of a farm.

Giles E. Hopkins, graduate of the Massachusetts Institute of Technology and active in the textile and research field, recently became technical director of the Wool Bureau, Inc., in New York City.

George H. Wise has been appointed head of the Nutrition Section of the Department of Animal Industry at the North Carolina State College and R. K. Waugh has been appointed head of the Dairy Husbandry Section.

Ralph W. Phillips, Chief of the Animal Industry Branch, Agriculture Division, Food and Agriculture Organization of the United Nations, has been appointed Deputy Director of the Agriculture Division of that Organization.

Walter Armer and H. H. Mayo, extension animal husbandman, University of Kentucky, and during the war with the War Department in Europe, recently left this country for a one to two year assignment as agricultural advisor in Greece under E.C.A.

K.F. Warner, extension meat specialist, U.S.D.A., is a member of the faculty at the summer school being conducted at the Colorado A. and M. College in June and July.

The forty-first annual meeting of the American Society of Animal Production, will be held at the Hotel Sherman in Chicago, Illinois, on November 25 and 26, 1949, with a dinner for the honored guest on November 27.